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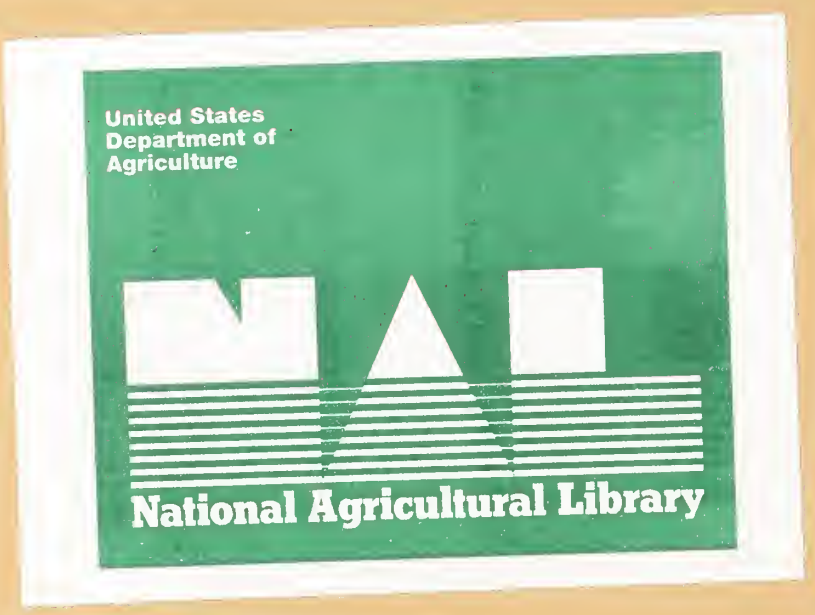

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Preface

This Heliothis/Helicoverpa working conference report and National Action Plan details an updated ARS fundamental and applied Heliothis/Helicoverpa research program in cooperation with universities and other state and federal agencies. A cooperative and cohesive team effort is being structured to help solve specific national problems related to this pest complex. This has required a detailed formulation of a comprehensive action program that clearly defines and states program goals and objectives, identifies each project relevance and role, identifies activities to reach the objectives, establishes time frames needed to reach objectives, and provides a basis for field participation of ARS scientists and cooperators in planning the program. This comprehensive plan should provide (a) focus and programmatic stability, (b) a basis for monitoring and evaluating program progress, (c) a basis for developing budget estimates and allocating resources, (d) responsiveness to the technology and problem-solving needs of state and federal action agencies, (e) identification of technology transfer opportunities and (f) development of team players and teamwork. The action plan contained herein should also provide an important foundation for program strengthening and expansion, coordination, decision-making, and implementation by the ARS National Program Staff.

The primary aim of the National Heliothis/Helicoverpa program is to provide the necessary research and team effort that will continue to yield environmentally and publicly acceptable, safe technologies for area-wide management and suppression of this pest complex. The technologies developed will continue to support the implementation of state and federal action and regulatory programs. ARS is supportive of the state and federal goals. The plan is designed to be dynamic yet responsive to the needs and priorities of our stakeholders. Progress in reaching goals will be reviewed on an annual basis. As the program progresses, participants will play a significant role in redefining essential activities when necessary, in eliminating some proposed activities that may result from the inherent uncertainties of research, and in assigning appropriate remaining activities or selecting new activities to achieve goals. This is the dynamic nature of the plan.

The National Program Staff expresses its gratitude and appreciation to all working conference attendees for participating in the organization and proceedings of the conference and in formulating this comprehensive action plan. We are especially indebted to the representatives from APHIS, CSRS, universities, state agencies, and the representatives from industry and commodity groups for their valuable interactions and contributions.

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Crop Protection

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Field Crop Entomology

Executive Summary

A major goal of the Agricultural Research Service (ARS) is the discovery of new principles and development of safer methods for controlling insects and other pests that infest agricultural commodities. Many major insect pests have already developed resistance to a number of current control methods that rely upon synthetic chemical pesticides, and the safety of these chemicals is increasingly being questioned. Research aimed at developing environmentally compatible and publicly acceptable pest management systems is a high priority for ARS.

The Heliothis/Helicoverpa complex has a world-wide distribution and contains some of the most serious pests to agriculture. H. virescens and H. zea are pests on a wide variety of crops including cotton, corn, soybean, lettuce, tomato, tobacco, ornamental, and other economic plants in the U.S. These devastating pests of field crops cost growers about $2 billion annually in yield losses and control costs. Currently, their control is achieved almost entirely through the use of synthetic organic insecticides. The desire to effectively manage Heliothis/Helicoverpa spp. using integrated control strategies that reduce pesticide dependency continues as a primary focus for ARS and others having a vested interest. Research emphasis and priorities established for ARS are: (a) host-plant resistance; (b) improved chemical control and pesticide application technology; (c) understanding the ecology and population dynamics of these pests; (d) behavior-modifying chemicals; (e) biological control; and (f) genetics, molecular biology, and basic physiology.

An ARS-wide working conference devoted to Heliothis/Helicoverpa was held on September 16-19, 1991, in San Antonio, Texas. This report of the conference contains an updated nationally coordinated 5-year action plan for Heliothis/Helicoverpa research in ARS. At present, around 18 ARS locations and about 90 ARS scientists are working on some aspect of basic and/or applied research aimed at this pest complex. These efforts involve entomologists, molecular biologists, organic chemists and biochemists, engineers, and insect and plant physiologists, including biocontrol scientists. Funding for this program amounts to some $4.98 million with much of the efforts involving extensive collaboration with federal and state agencies, universities, and industry as outlined in the action plan.

The action plan utilizes the adapted Convergence Technique for Agricultural Research (ACTAR) and is organized into a series of arrays to obtain the specified program objectives within the 5-year timeframe. These include lead, safeguard, optimizing, and supplementary array activities and will provide a basis for budget development and monitoring progress of the program.

ARS Mission and Needs for Environmentally Compatible Insect Management

The Agricultural Research Service (ARS) is the Department's principal intramural research agency. It has long-standing working relationships with the other research agencies in the Department, the State Agricultural Experiment Stations, and the private research sector. The ARS also works closely with the action agencies in the Department and serves as the research arm for many of them. Interagency programs within the Department are critical in such areas as soil and water conservation, range improvement, control of plant and animal diseases, and food safety.

The mission of the ARS is--

> To plan, develop, and implement research that is designed to produce the new knowledge and technologies required to assure the continuing vitality of the Nation's food and agricultural enterprise. As a Federal research agency, ARS (1) addresses problems that are of legitimate national concern, (2) conducts research that is appropriate for the Federal Government, and (3) exploits the unique capabilities of ARS scientists and the facilities they operate - a combination that forms an integrated and coordinated national resource that is not duplicated by others in the full U.S. agricultural research and development system.

During the past few decades the consumer public has insisted on development of safer pest control methods to supplement and offset extensive reliance on synthetic organic chemical pesticides. Progress has been made in such areas as host plant resistance, expanded use of predators, parasites and pathogens, semiochemicals (pheromones, plant attractants, repellents, etc.), insect sterility, biotechnology, cultural control and overall insect pest management. Although good progress has been made at developing biologically-based methods of pest control, synthetic chemical pesticides are still our major means of protecting our food and fiber crops from pests. New, environmentally compatible pest control technologies are slowly replacing synthetic pesticides. This will be an even more critical issue as more registered pesticides are banned. Increased research focus on host-plant resistance, chemical control and application technology, insect ecology and population dynamics, behavior modifying chemicals, biological control, and insect genetics, molecular biology, and basic physiology is needed, and is viewed as one of the high priority areas of research for ARS in addressing agricultural problems caused by Heliothis/Helicoverpa.

Objectives and Charge to the Workshop

The overall charge of the ARS-wide working conference was to update the USDA-ARS action plan and will encompass fundamental and applied Heliothis/Helicoverpa research in close cooperation with university collaborators and state and federal agencies. The working conference was specifically designed to provide a forum for expressing views, generating ideas, and identifying gaps, needs and areas of cooperation leading to technologies for area-wide management and suppression of Heliothis/Helicoverpa insects.

Specific objectives were to:

1. Provide an opportunity for a research update and exchange of research ideas and to facilitate cooperation between groups currently involved in Heliothis/Helicoverpa research.

2. Develop an up-to-date comprehensive and nationally coordinated action plan for Heliothis/Helicoverpa research in ARS.

3. Provide an opportunity for input into the development of the ARS Heliothis/Helicoverpa research program by action and state agencies.

4. Identify technology gaps in the ARS Heliothis/Helicoverpa research program.

5. Establish priorities for Heliothis/Helicoverpa research.

The comprehensive action plan is divided into six major action areas, each of which describe activities to be carried out over a 5-year time frame. These activities are comprised of up to four arrays as outlined by the adapted Convergence Technique for Agricultural Research (ACTAR)[1/];

1. Lead array (LEAD) -- the main effort and includes activities considered most plausible for successful achievement of a phase of work.

2. Safeguard array (SAFEGD) -- includes activities which are the most likely substitute technical approaches to the activities in the lead array; activities in this array constitute the essential protection of the outcome of the program against the inherent uncertainties of activities in the lead array.

3. Optimizing array (OPTIM) -- are activities which could enhance or optimize the potential of activities in the lead array to achieve the intermediate objective of the phase of work.

4. Supplementary array (SUPPL) -- activities for which the probability of a positive contribution to the phase of work or objective is unknown; the results, however, could bring about major changes in the lead array. Some of these activities may be "high risk" or "far out" applied research and some may be long range or fundamental research. At least some of these activities are essential to protect the lead array from uncertainties of outcome and to encourage unusual technical approaches.

1/ Shea, K. R. and N. D. Bayley. 1976. A new approach for planning and coordination of a large project. Office of the Secretary, USDA, Washington, DC.

Historical Perspectives of National *Heliothis* Suppression Plan

Julius J. Menn
USDA, ARS, Plant Sciences Institute
Beltsville, Maryland 20705

It has been recognized by the entomological community that control of the *Heliothis*/*Helicoverpa* complex is likely the most complex insect management problem encountered in the field to date. The multi-host range, long-distance migration potential, high fecundity, and adaptation to chemical insecticides are some of the factors contributing to the difficult economic management of this insect complex.

In 1985, E. B. Knipling, then Associate Deputy Administrator, National Program Staff, appointed a coordinating leadership team consisting of Julius J. Menn, Edgar G. King, and Charlie E. Rogers to develop a unified National *Heliothis* Suppression Program (NHSP).

An exhaustive analysis of ARS resources, in 1985/1986, revealed that there were 53 scientist years (SY's) in 25 research units, in 17 locations, in 12 states, and in Behoust, France, engaged in various aspects of *Heliothis* research. Distribution of the research effort by control approach in percent showed: 26% in biology; 24% in IPM; 17% in host plant resistance; 13% in genetics; 9% in behavior; 7% in chemical control and 2% in cultural methods.

A comprehensive plan was developed in consultation with all scientists involved in these efforts. Research was divided into short- and long-range research leading to suppression tests on a wide area and directed to potential technology transfer to user groups. All inputs were analyzed by use of the Program Evaluation and Review Technique (PERT). Based on this information, research was divided into short term (< 5 years) and long term (> 5 years) activities.

In the short term, resources have been earmarked for research on: biological-, chemical-, microbial-, genetic-control, and host plant resistance (HPR). In the long term, research was targeted towards development of behavioral and non-classical biological control methods including: *In vitro* mass rearing technology for *Heliothis*/*Helicoverpa* parasites, semiochemicals and attractants, fundamentals of pheromone production and release in the insect and disruption of reproduction, behavioral confusion and development of hybrid sterility technology.

A comprehensive proposed action plan was submitted to E. B. Knipling in January 1987 with recommendations including reallocation of Heliothis research resources into six action areas:

1) Heliothis movement and monitoring
2) Genetic control
3) Chemical and microbiological control
4) Augmentation of predators and parasites
5) Semiochemicals
6) Decision-making technology

With the reassignment of Julius Menn to the Plant Sciences Institute at BARC, the NHSP assignment was transferred to the Field Crop Entomology, NPL position. D. D. Hardee assumed that responsibility in April 1988, during his tenure on NPS.

References:

King, E. G. and C. E. Rogers. 1987. ARS National Heliothis suppression program (ARS-NHSP). To: Action Area Coordinators. Jan. 22, 1987.

Menn, J. J., E. G. King, and R. J. Coleman. 1989. Future control strategies for Heliothis in cotton. In: Pest Management in Cotton. Green, M., B. Lyon, D. J. de (Eds.) pp. 101-121, SCI, Ellis Horwood Ltd. Chichester, England.

Action Area 1 - Host Plant Resistance

Introduction

Numerous agricultural leaders over the past 25 years have emphasized the need for nonchemical control of insect pests. However, Headley (1979) predicted that chemical control would have a major role in pest management in value crops until 1992 and then the trend for nonchemical control methods would increase. Headley also predicted that resistant cultivars would have a major role in controlling pests in crops from 1979 and that after 1992 the demand for their use would sharply increase.

Plant resistance has been defined as "the heritable qualities of the plant that influence the ultimate degree of damage done by the insect." There are three mechanisms of resistance that may impact the damage done by the pest insect: nonpreference, antibiosis, and tolerance. These mechanisms may operate independently or together in a cultivar to lessen insect damage and/or populations. The resistant cultivar may be used as the sole method of control to limit insect damage on the farm or as a foundation to other components of integrated pest management. Plant resistance to insects, integrated with other biological strategies, should be one of the principle means of nonchemical control of Helicoverpa and/or Heliothis spp. In fact, most likely, plant resistance as well as other components of integrated pest management will be required to be used together before a significant impact can be made on these pest insect populations.

Major Accomplishments

A number of resistant cultivars have been developed and recently released: cotton; nectariless germplasm, MD 51 ne (Stoneville); 12 germplasm lines (Mississippi State); corn; 6 inbreds, 2 populations (Tifton); soybeans; Lamar cultivar and 1 advanced breeding line, D75-1069 (Stoneville); tobacco; advanced breeding line, I-514 (Oxford, Athens).

New sources of crop germplasm resistant to Helicoverpa and/or Heliothis continue to be identified and/or factors or chemicals have been introduced into existing germplasms (Ames, Columbia, Mississippi State, Stoneville, Tifton, College Station, Albany, Oxford, Athens).

Biological factors adversely affecting insect growth and development have been described in corn (Tifton, Columbia, Ames); cotton (Mississippi State, College Station, Stoneville); soybean (Stoneville); tobacco (Oxford, Athens), and tomato (Albany).

Mechanisms of resistance and at least some of the basis of resistance, including the genetics and biochemistry, have been described and/or found: corn (Tifton, Ames, Columbia); tobacco (Oxford); cotton (Mississippi State, Stoneville, College Station); potato (Albany); soybean (Stoneville).

New and novel approaches are now being developed at College Station and Mississippi State that include the use of transgenic plant development and testing.

New and/or modified technology for use in plant resistance studies or for developing new plant resistance cultivars and/or germplasms continue to be reported, such as those for chemical or genetic assays. (Cotton: Mississippi State, Stoneville, College Station; Corn: Tifton; Soybeans: Stoneville; Tobacco: Oxford; Potato: Albany)

Basic studies have shown compatibility of corn plant resistance and an insect pathogen, a predator, an insecticide, and inherited sterility as components of integrated pest management (Tifton).

Significance

Technological developments made by plant resistance scientists now enable them to more effectively identify new resistant germplasm; identify chemicals and genes conferring resistance; and to insert foreign genes (Bt) into domestic plants. Cottons containing the Bt gene are projected to be available by 1995. Experimental resistant corn and cotton have shown population reduction by as much as 50-65%/generation. Sufficient germplasm of all crops is available to reduce losses by Heliothis/Helicoverpa spp. by as much as 5-10%. New technology and the combination of plant resistance and other components of integrated pest management should reduce losses by Heliothis/Helicoverpa spp. by as much as 50%.

Cooperators/Co-investigators

Researchers involved with the direction of ARS research on Heliothis and/or Helicoverpa studies have involved themselves, in some cases, more closely with industry such as hybrid corn seed companies, cotton seed companies, tobacco companies, and those biotech companies developing transgenic plants and/or those involved in transfer of genes through RFLP analysis.

Lead ARS Scientists

Code	Name	SY	Location
JAE	J. A. Eash	0.5	Albany, CA
CAE	C. A. Elliger	0.5	Albany, CA
ACW	A. C. Waiss	0.5	Albany, CA
RLW	R. L. Wilson	0.2	Ames, IA
RFS	R. F. Severson	0.1	Athens, GA
MES	M. E. Snook	0.1	Athens, GA
DWA	D. W. Altman	0.7	College Station, TX
BDB	B. D. Barry	0.1	Columbia, MO
LLD	L. L. Darrah	0.1	Columbia, MO
JNJ	J. N. Jenkins	0.6	Mississippi State, MS
WLP	W. L. Parrott	0.9	Mississippi State, MS
DMJ	D. M. Jackson	0.6	Oxford, NC
LL	L. Lambert	0.1	Stoneville, MS
WRM	W. R. Meredith	0.1	Stoneville, MS

REL	R. E. Lynch	0.1	Tifton, GA
NWW	N. W. Widstrom	0.4	Tifton, GA
BRW	B. R. Wiseman	0.5	Tifton, GA

The scientists involved in Heliothis and/or Helicoverpa research continue to utilize many other ARS scientists listed herein to broaden their research scope and to increase the depth of their work as well as numerous state and commercial scientists.

ARS Cooperators

Name	Location
D. W. Ow	Albany, CA
L. M. Pollak	Ames, IA
O. T. Chortyk	Athens, GA
W. S. Schlotzhauer	Athens, GA
W. W. Cantelo	Beltsville, MD
F. E. Callahan	Mississippi State, MS
P. A. Hedin	Mississippi State, MS
J. C. McCarty	Mississippi State, MS
V. A. Sisson	Oxford, NC
J. E. Carpenter	Tifton, GA
L. D. Chandler	Tifton, GA
H. R. Gross	Tifton, GA
J. J. Hamm	Tifton, GA
C. C. Holbrook	Tifton, GA
M. G. Stephenson	Tifton, GA

Non-ARS Scientists

Name	Affiliation	Location
Ken Ziegler	Iowa State Univ.	Ames, IA
Karl Espelie	Univ. of Georgia	Athens, GA
George Teetes	Texas A&M Univ.	College Station, TX
Kenneth Sink	Michigan State Univ.	E. Lansing, MI
Albert Johnson	Clemson Univ.	Florence, SC
Robert Miller	Univ. of Tenn.	Greenville, TN
Gary Reed	Oregon State Univ.	Hermington, OR
David J. Isenhour	Pioneer Hi-Bred	Johnston, IA
Mark Nielson	Univ. of Kentucky	Lexington, KY
George Wagner	Univ. of Kentucky	Lexington, KY
John Foster	Univ. of Nebraska	Lincoln, NE
Tom Archer	Texas A&M Univ.	Lubbock, TX
Roy Creech	Miss. State Univ.	Mississippi State, MS
Randy Luttrell	Miss. State Univ.	Mississippi State, MS
Stan Surplick	Miss. State Univ.	Mississippi State, MS
--	RJR Tobacco Co.	North Carolina
Randy Deaton	Monsanto	St. Louis, MO
Harry Collins	Delta Pine Land Seed Co.	Shaw, MS
Keith Jones	Delta Pine Land Seed Co.	Shaw, MS
Dirk Benson	Garst Seed Co.	Thomasville, GA
W. D. Branch	Univ. of Georgia	Tifton, GA

Robert McPherson	Univ. of Georgia	Tifton, GA
J. A. Mihm	CIMMYT	El Batan, Mexico

Research Gaps and Bottlenecks

1. Need a better marker selection method for identification of genes to be used in commercial breeding programs.

2. Lack of knowledge in insect and plant behavior and physiology as they relate to plant resistance studies.

3. Strong need for additional research on insect rearing to yield a higher quality of insects for plant resistance research.

Research Constraints

1. To provide sufficient data to convince commercial breeders to accept resistant cultivars.

2. Provide additional funds for evaluating germplasm and integrating resistant cultivars into IPM.

Action Area 1 - Host Plant Resistance

		Year 1	Year 2	Year 3	Year 4	Year 5
LEAD 1.1	Develop crop cultivars and/or germplasms with high resistance to reduce numbers of and damage from Helicoverpa/Heliothis spp.	Identify crop cultivars and/or germplasm with high levels of resistance to corn earworm and tobacco budworm	Begin initial plans to incorporate resistant germplasms into breeding and/or development program	Continue as in yr 2	Continue as in yr 3	Release resistant cultivars and/or germplasms to public and/or begin testing for mechanisms of resistance, basis of resistance, or for effectiveness of resistant plants in the management of the pest
		DWA, DMJ, RLW, LL, JNJ, WRM, WLP, NWW, BRW	SAME	SAME	SAME	SAME
SAFEGD 1.1.1	Identify and/or develop new sources of resistance that impact on populations of Helicoverpa/Heliothis spp.	Same as yr 1 in objective 1	Same as yr 2 in objective 1	Same as yr 3 in objective 1	Same as yr 4 in objective 1	Same as yr 5 in objective 1
		JAE, BDB, DMJ, DWA, LLD, LL, CAE, JNJ, REL, BRW RLW, WLP, ACW, MES, RFS	SAME	SAME	SAME	SAME
OPTIM 1.1.2a	Determine the effectiveness of the resistant cultivar and/or germplasm in reducing populations of Helicoverpa/ Heliothis spp.	Determine in the laboratory the impact of the various effects of the resistant cultivar and/or germ-plasm on the life cycle of the resisted pest insect	Continue as in yr 1	Initiate field testing as in yr 1	Continue as in yr 3	Continue as in yr 4
		JNJ, BRW, WLP, RLW, DMJ, LL, WRM	SAME	SAME	SAME	SAME

Action Area 1 - Host Plant Resistance

		Year 1	Year 2	Year 3	Year 4	Year 5
OPTIM 1.1.2b	Determine the interactions of plant resistance to Helicoverpa/Heliothis spp. with other methods of integrated pest management	Determine the effectiveness of combining plant resistance and one other method of integrated pest management	Continue as in yr 1	Determine the effectiveness of adding an additional component of integrated pest management to that of yr 1	Continue as in yr 3	Initiate plans for a pilot testing
		JNJ, BRW, WLP, WRM, LL, DWA	SAME	SAME	SAME	SAME
OPTIM 1.1.2c	Develop transgenic plants and select new resistance genes for plant transformation	Identify new sources of genes from non-crops	Evaluate new plant resistance genes	Same as in yr 2	Same as in yr 3	Develop method for introduction of foreign genes into crop plants
		ACW, DWA, JNJ, WLP, DMJ, LL, WRM, NWW, BRW, RFS	SAME	SAME	SAME	SAME
SUPPL 1.1.3	Develop plant resistance technology that would impact or alter the course of action of any one of the other arrays	Initiate studies that could alter the course of direction and/or enhance the activity of any array described herein	Same as in yr 1	Same as in yr 2	Same as in yr 3	Same as in yr 4
		JNJ, LLD, WLP, BDB, DMJ, REL, LL, BRW	SAME	SAME	SAME	SAME
LEAD 1.2	Determine the biological, biochemical, and/or biophysical mechanisms of resistance to Helicoverpa/Heliothis spp.	Conduct laboratory and/or field studies to determine effects and interactions of the resisted plant materials on the pest insect	Continue as in yr 1 and initiate studies to determine the basis of the resistant plant materials	Continue as in yr 2	Continue as in yr 3 and initiate studies on the interactions of the pest and the resistant plant materials and environment	Continue as in yr 4
		JAE, DMJ, CAE, ACW, JNJ, LL, NWW, WLP, BRW, RLW, MES, RFS	SAME	SAME	SAME	SAME

Action Area 1 - Host Plant Resistance

		Year 1	Year 2	Year 3	Year 4	Year 5
OPTIM 1.2.2a	Same as 1.1.2a					
OPTIM 1.2.2b	Same as 1.1.2b					
SUPPL 1.2.3	Determine the genetic basis of the resistant plant materials and/or identified chemical(s) factors	Develop the necessary technology to accomplish the objective	Initiate the crosses and subsequent generations to prepare for the genetic analysis	Initiate the genetic studies through standard procedures or RFLP analysis	Continue as in yr 3	Initiate plans to move the genes into adapted cultivars and/or germplasms
		ACW, LL, JAE, NWW, DWA, BRW, JNJ, RLW, WLP	SAME	SAME	SAME	SAME

Action Area 2 - Chemical Control and Application Technology

Introduction

Suppression of Heliothis/Helicoverpa populations with chemical and biological insecticides remains the major component in crop management systems in most corn, cotton, peanut and soybean production areas. Insecticides are most beneficial when used in conjunction with cultural and biological management techniques. For example, several studies have shown that timely application of insecticides can aid in Heliothis/Helicoverpa management without severe disruption in beneficial insect populations. However, problems do exist with insecticide-based management programs. Insecticide resistance, lack of adequate insecticide formulations, crop phytotoxicity, and environmental contamination can create difficult management situations, but these problems could be effectively managed with increased knowledge of the systems in which Heliothis/Helicoverpa operate. Additional information is needed to facilitate understanding of the Heliothis/Helicoverpa ecosystem, and to provide technological advances for improved insecticide-based crop management systems.

Major Accomplishments

Pest control.

Determined effects of volumes and rates of various insecticides on Heliothis/Helicoverpa mortality (Stoneville). Demonstrated that pyrethroids mixed with non-EC oil and applied in irrigation water provided longer residual control of H. zea on cotton than did pyrethroids mixed with water (Tifton). Showed that ovicide efficacy is dominated by mortality of neonate larvae rather than mortality of eggs (College Station).

Demonstrated that pyrethroids applied in irrigation water provided Heliothis/Helicoverpa control as good as that achieved with ground applications (Tifton). Observed no differences in control of H. virescens using microencapsulated capsule suspensions of profenofos when compared to an EC formulation of profenofos (College Station). Determined that efficacy of polymeric controlled release formulations of sulprofos on H. virescens was greater than with sulprofos and other polymeric formulations (College Station).

Evaluated and identified new insect growth regulators for H. zea control (Tifton). Demonstrated defensive role of mycotoxins and other fungal metabolites against H. zea (Peoria). Demonstrated the ability of H. zea detoxification systems to respond to mycotoxins (Peoria).

Insecticide resistance.

Determined that no cross resistance to carbamates and organophosphates was present in pyrethroid-resistant H. virescens (Stoneville). Determined that inheritance of pyrethroid resistance in resistant H. virescens strain was co-dominant and indicative of the presence of a major metabolic detoxification mechanism (Stoneville). Analyzed and

developed hypotheses concerning inheritance of resistance to methyl parathion and EPN in H. virescens (Phoenix, Weslaco).

Identified resistance to thiodicarb in H. virescens populations that were resistant to pyrethroids (Stoneville). Confirmed resistance to pyrethroid, carbamate, and organophosphate insecticides (multiple resistance) in H. virescens populations in Louisiana and Mississippi (Stoneville). Determined season-long levels of resistance to pyrethroid, carbamate and organophosphate insecticides in naturally occurring H. virescens populations (Stoneville). Determined that no resistance present to pyrethroids in H. virescens/H. zea populations and no resistance present to methomyl in H. zea populations in south Texas and northeast/northwest Mexico (Weslaco). Observed variations in H. zea resistance to organophosphates in Cental America, southwestern Chiapas, Mexico, and south Texas (Weslaco).

Application technology.

Determined that insecticide droplet size is a factor in the efficacy of ovicides; some formulations are more effective with large droplets, while others more effective with small droplets (College Station). Determined that efficacy of some pyrethroids was influenced by droplet size; large drops increased efficacy on the leaf (College Station, Stoneville). Showed that insecticide formulations can cause differences in droplet size distributions which can adversely affect efficacy (College Station).

Investigated the use of air-assist atomizers for low volume ground application of insecticides in water and oil diluents (Stoneville). Developed improved drop-on-demand device (Stoneville). Developed new application/measuring systems for conduction of droplet size investigations (College Station, Stoneville, Tifton).

Determined best irrigation nozzle packages for application of insecticides (insectigation) to control H. zea infesting corn (Tifton). Determined effects of equipment, formulation, and operational variables on size of spray droplets produced by aircraft delivery systems (College Station). Determined effects of aerial application variables on insecticide deposition of spray drops in cotton (College Station).

Significance

Information developed by scientists working in chemical control and application technology has increased the efficiency of insecticides recommended for Heliothis/Helicoverpa management, and has established guidelines for selection of proper rates, formulas and spray volumes of these insecticides. Studies have identified mechanisms involved in H. virescens insecticide resistance and have provided baseline information for the establishment of resistance management programs. Additionally, research results have served as guides to industry for the development, selection and proper operation of spray nozzles and associated sprayer components for enhanced insecticide efficacy and reduced environmental contamination.

Cooperators/Co-investigators

Lead ARS Scientists

Code	Name	SY	Location
LFB	L. F. Bouse	0.2	College Station, TX
IWK	I. W. Kirk	1.0	College Station, TX
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PFD	P. F. Dowd	0.2	Peoria, IL
ACB	A. C. Bartlett	0.1	Phoenix, AZ
TJH	T. J. Henneberry	0.1	Phoenix, AZ
GWE	G. W. Elzen	0.5	Stoneville, MS
JEM	J. E. Mulrooney	0.5	Stoneville, MS
WPS	W. P. Scott	0.4	Stoneville, MS
ACW	A. C. Womac	0.2	Stoneville, MS
LDC	L. D. Chandler	0.4	Tifton, GA
HRS	H. R. Sumner	0.5	Tifton, GA
DAW	D. A. Wolfenbarger	0.9	Weslaco, TX

ARS Cooperators

Name	Location
S. D. Pair	Lane, OK
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B. S. Shasha	Peoria, IL
J. J. Hamm	Tifton, GA
J. E. Carpenter	Tifton, GA
J. R. Raulston	Weslaco, TX

Non-ARS Cooperators

Name	Affiliation	Location
Jerry B. Graves	Louisiana St. Univ.	Baton Rouge, LA
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M. Firko	APHIS	Hyattsville, MD
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Carroll D. Applewhite	FMC	Tifton, GA
Richard B. Chalfant	Univ. of Georgia	Tifton, GA
Gary A. Herzog	Univ. of Georgia	Tifton, GA
J. Norman	Texas A&M Univ.	Weslaco, TX
D. Riley	Texas A&M Univ.	Weslaco, TX
Alton N. Sparks, Jr.	Texas A&M Univ.	Weslaco, TX
M. Gonzalez	Ciba-Geigy	Torreon, Mexico
E. Martinez	CATIE	Managua, Nicaragua
E. Salgado	INIFAP	Tampico, Mexico

Research Gaps and Bottlenecks

1. Research to extend field viability of biological insecticides (at least 7 days) and develop improved biological insecticide formulations.

2. Develop strategies for use of Bt's in field situations - develop management strategies to eliminate population fluctuations, study sublethal effects, application strategies, etc.

3. Develop simulated cropping systems to evaluate management strategies.

4. Expand opportunities for research on natural products.

5. Expand studies on insect/insecticide genetics for determining mechanisms of resistance.

6. Expand studies on insecticide-plant-insect interactions to include biological insecticides.

7. Studies to integrate insecticide interactions, resistance management, and transgenic plants.

8. Expanded cooperation with formulation chemists at regional labs.

9. Alternatives to pyrethroids.

10. Evaluation of band applications for ways to reduce insecticide rates, etc. in ground application.

11. Earlier involvement of application technology in insecticide evaluation.

Bottlenecks: (1) money; (2) personnel; (3) no insects to work on in certain locations during certain years; (4) technology transfer.

Research Constraints

None

Action Area 2 - Chemical Control and Application Technology

		Year 1	Year 2	Year 3	Year 4	Year 5
LEAD 2.1	Identify effective commercially available chemical insecticides and biorationals (including biologicals, IGRs, feeding stimulants and attractants) and determine optimal management strategies for Helicoverpa/Heliothis on important agronomic crops (corn, cotton, peanuts, soybean, etc.)	Conduct laboratory and field experiments on various crops to determine efficacy of available compounds using lab colony and field-collected insects	Select best candidate compounds from both chemical insecticide and biorational groups for further lab and field testing. Begin screening for resistance to the best candidate insecticides and determine effects of candidate insecticides on non-target organisms (parasites, predators, aquatic fauna, etc.)	Integrate best candidate insecticides into studies to develop optimal control strategies [timing of applications, improved application technology, management of resistance, refinement of thresholds and integration with cultural, biological (including pheromones) and host plant resistance control methods]	Continue as in yr 3	Continue as in yr 4 with goal to have optimal field control package in place for evaluation of pilot test of Helicoverpa/Heliothis control over large area in all above named crops
		LDC, GWE, MAL, DAW	SAME	SAME	SAME	SAME
SAFEGD 2.1.1	Identify new insecticides/biorationals and/or application techniques for optimization of Lead Arrays 2.1 and 2.2	Conduct laboratory studies designed to develop and/or evaluate new experimental insecticides/ biorationals and initiate studies to improve application precision (swath guidance, rate control and measurement, speed sensing, and efficiency through reduction of loss due to drift and non-target deposits) for ground and aerial spraying systems	Continue as in yr 1 and initiate studies to determine resistance and effects of compounds on non-target organisms using best new insecticides/ biorationals	Initiate field testing of best new insecticides/ biorationals where warranted, and expand field testing of new application techniques	Continue as in yr 3 and integrate with Lead Arrays 2.1 and 2.2	Continue as in yr 4
		LFB, LDC, IWK, PFD, MAL JEM, ACW, HRS	LFB, LDC, IWK, PFD, MAL, JEM, ACW, GWE, DAW, HRS		SAME	SAME SAME

Action Area 2 - Chemical Control and Application Technology		Year 1	Year 2	Year 3	Year 4	Year 5
OPTIM 2.1.2a	Develop improved formulations of candidate insecticides/ biorationals	Identify and determine insecticide formulation and carrier needs and conduct preliminary lab studies designed to evaluate these materials	Continue as in yr 1 and initiate small plot tests on weed sites for early season control and on major crop hosts	Continue as in yr 2	Continue as in yr 3 and begin integration into Lead Array 2.1	Conduct field tests fully integrated into Lead Array 2.1
		LDC, MAL, PFD, GWE, JEM, DAW, TJH	SAME	SAME	SAME	SAME
OPTIM 2.1.2b	Develop improved insecticide application methodology for creation of optimal droplet sizes, reduction in drift, and increased probability of deposition onto the target	Conduct experiments to determine parameters that affect drop size drift, deposition, etc.	Continue as in yr 1	Integrate information achieved in yrs 1 and 2 and initiate field testing to optimize spray technology	Continue as in yr 3 with developments used to supplement studies in Lead Arrays 2.1 and 2.2	Continue as in yr 4
		IWK, LFB, JEM, WPS, ACW, HRS	SAME	SAME	SAME	SAME
SUPPL 2.1.3a	Conduct studies to determine environmental fate of best candidate insecticides/ biorationals using various application systems	No studies conducted	Begin preliminary examination of residues of candidate compounds from various crops	Initiate studies on aerial, groundwater, and runoff fate of candidate compounds	Continue as in yr 3	Continue as in yr 4
			LDC, HRS	LDC, HRS, IWK, LFB	SAME	SAME
SUPPL 2.1.3b	Conduct studies to develop a theory of inheritance of insecticide resistance and to determine insecticide resistance mechanisms	Initiate lab studies to evaluate levels of resistance to selected groups of insecticides on different populations of insects and to determine how resistance is carried in populations	Continue as in yr 1	Continue as in yr 1	Integrate findings into optimal management programs and continue studies as in yr 1	Continue as in yr 4
		GWE, DAW, ACB	SAME	SAME	SAME	SAME

Action Area 2 - Chemical Control and Application Technology

		Year 1	Year 2	Year 3	Year 4	Year 5
SUPPL 2.1.3c	Conduct studies to develop insecticide resistance management strategies for Helicoverpa/Heliothis	Initiate studies designed to determine effects of various insecticides on insecticide resistance GWE, DAW	Continue as in yr 1 and increase emphasis on evaluating new management strategies based on timing of applications, insecticide combinations, insecticide use patterns, etc. SAME	Continue as in yr 2 and integrate findings into optimal management program GWE, DAW, MAL, LDC	Continue as in yr 3 SAME	Continue as in yr 4 SAME
LEAD 2.2	Determine and compare optimal insecticide application techniques utilizing best available technology (aerial, ground-rig, chemigation, etc.) to improve application methods for improved efficacy and lower environmental impact of currently used chemical insecticides and biorationals	Conduct experiments using available or new application systems in the field on various crops or in the lab that emphasize effects of spray volumes, carriers, concentration, droplet size, percent coverage, placement, release rate, etc. on effects of candidate insecticides/biorationals studied in Lead Array 2.1, yr 1 LFB, IWK, JEM, HRS, ACW	Continue studies as in yr 1 using best candidate insecticide/ biorationals SAME	Continue as in yr 2 and begin integrating with studies to determine optimal control strategies SAME	Continue as in yr 3 SAME	Continue as in yr 4 with goal to develop package for use in pilot test from Lead Array 2.1 SAME
SAFEGD 2.2.1	Same as 2.1.1					
OPTIM 2.2.2	Same as 2.1.2b					

Action Area 2 - Chemical Control and Application Technology

		Year 1	Year 2	Year 3	Year 4	Year 5
SUPPL 2.2.3	Elucidate mechanisms of insecticide transfer from plant surface to insect (persistence of insecticide on plant)	Initiate lab studies to determine mechanisms using select candidate insecticide JEM, ACW	Continue as in yr 1 SAME	Integrate lab studies with knowledge from other arrays to optimize application of insecticides to plant surfaces and to improve formulations, carriers, etc. JEM, ACW, WPS	Continue as in yr 3 SAME	Continue as in yr 4 SAME

Action Area 3 - Ecology and Population Dynamics

Introduction

The Heliothis/Helicoverpa complex has a world-wide distribution and contains some of the most serious pests to agriculture. In most regions, agroecosystems provide only transient habitats for these highly-mobile pests, and a thorough knowledge of their ecology, behavior and movement is critical for developing sound control technologies that do not rely on the field-by-field application of "hard pesticides".

Four critical phases of research have been identified in ecology and population dynamics.

Adult behavior, including 1) refinement of technology for determining nocturnal adult behavior, 2) determination of post-emergence preflight activities, and factors that affect these behaviors, and 3) behavioral interactions between adults and plants used for either reproduction or feeding sites, and plant-produced food attractants and feeding stimuli.

Long and short-range movement, including 1) development of technology, 2) determination of physical and biological factors that affect dispersal, and 3) determination of intra- and interregional movement and its impact on population dynamics.

Development of pest management decision aids, including 1) optimization of cotton production and protection models, 2) implementation of multiple pest-species interactions into existing models, and 3) integration of existing models dealing with cotton production and cotton protection.

Population dynamics, including 1) identification and characterization of source population zones, 2) determination of the impact of migrant populations in recipient regions, and 3) determination of spatial and temporal patterns of populations developing within different regions and their interactions.

Major Accomplishments

Adult behavior. Recent research has defined the emergence behavior of Helicoverpa zea under field conditions. These studies quantified the adult emergence profile in maturing corn fields through the night as well as their post-emergence activity patterns and behavior. Initial flight activities, including boundary layer flight behavior and pheromone trap responses of newly emerged moths dispersing in a vegetable ecosystem, also were determined. This research resulted in a demonstration that emerging moths could be killed prior to their initial flight activity using feeding baits formulated with insecticide. (College Station, TX; Weslaco, TX; Lane, OK)

Long and short-range movement. Refinement and application of radar systems (airborne, and scanning and vertical groundbased) have resulted in the quantification of events associated with migratory movement of Helicoverpa zea. Scanning radars have been used to document the flight

of billions of corn earworm and fall armyworm moths from concentrated source areas as well as flight over downwind areas. This research quantified insect flux, vertical distribution and density, flight altitude, orientation and nightly variation of insect flux during emergence periods. Other entomological radar research has indicated the feasibility of classifying airborne insect targets based on target size, shape, and orientation. Development and use of the first airborne radar in the U.S. has resulted in the quantification of downwind and crosswind dispersal of migrating clouds of corn earworm leaving a source area. The airborne radar was used to document a 1-night flight of insects initiating flight from corn fields in the Rio Grande Valley of Texas and northern Tamaulipas, Mexico, to San Antonio, Texas, a distance of over 400 km. Associated meteorological studies of nocturnal atmospheric boundary layer characteristics during peak corn earworm dispersal periods have shown that migrating adults layer at altitudes of low-level wind maxima (nocturnal low-level jets), and that these low-level jets significantly impact insect dispersal. Other meteorological research, combined with airborne radar tracking, indicated a close fit between projected moth cloud displacement based on atmospheric trajectories at 500 m and actual displacement. However, differences between the atmospheric trajectory and successive insect cloud displacements revealed significant spatial and temporal gaps in NWS rawinsonde data and/or active moth flight affecting displacement distance and direction. Meteorological research has also been used to "back track" resistant tobacco budworm populations from recipient to donor regions. (Tifton, GA; College Station, TX; Weslaco, TX)

Development of pest management aids. Over the past 3 years, an insect management model (rbWHIMS) has been developed that aids in pest management decisions. Presently, 9 pest species are incorporated into the model. Data concerning the pest and crop status are entered into the model, which subsequently generates a scouting report that includes detailed information on the status of the crop and pests, as well as recommendations for single-pest species and all pest species combined. Extensive validation tests have been conducted on the model, and revisions presently are being included.

A simulation model of insect spatial dispersion and density in cotton has also been developed. This model has aided in the development of a sampling plan for scouting cotton insects using Bayesian methods. This research has resulted in the development of a scouting protocol for cotton in the Midsouth that presents a unified sampling plan for the principal pest species over the entire season. This scouting protocol considers changes that occur in the pest complex relative to the growth of the host plant, and can be used by consultants, extension personnel, etc. (Mississippi St., MS) Other recent research has resulted in the development and refinement of methods to detect and quantify adult populations. This research has resulted in the development and standardization of pheromone baits used for capturing males in pheromone traps, and the development of electromechanical counting systems for tabulating captures. These systems have been used to quantify capture profiles of male Heliothis/Helicoverpa spp. through the night and throughout the season. (Stoneville, MS; College Station, TX)

Population dynamics. Recent research on the population dynamics of Helicoverpa zea has shown that fruiting corn is the major nursery crop that produces adult populations which are available for local dispersal and long-distance migration. These studies indicated that populations of corn earworm developing on whorl-stage corn tended to remain localized in specific corn-growing regions, producing the infestation on fruiting corn. Regional surveys of populations in corn indicated that up to 30,000 corn earworm adults could be produced per hectare of fruiting corn. This research formed the basis of studies which documented the long-distance migration of this insect and resulted in the concept of suppressing populations in source areas prior to migratory flights. Preliminary regional studies have shown that standardized data collection within different cropping regions can aid in determining the impact of migratory populations by characterizing the chronology of populations developing between regions. These studies also have indicated that a reverse fall migration of corn earworm from more northerly latitudes also occurs. (Weslaco, TX; Tifton, GA; College Station, TX)

Identification of pollens adhering to the bodies of corn earworm males captured in traps in Oklahoma showed that the most northerly possible origin of these adult populations was south Texas. A significant percentage of the moths had citrus pollen adhering to their bodies. These studies have shown that pollen identification can be used to determine the plants that are attractive to moths and the possible origin of spring populations within different regions. (College Station, TX; Weslaco, TX; Lane, OK)

Research in Arizona has demonstrated the occurrence, initiation, and termination of Heliothis virescens summer diapause and the influence of high temperature on this diapause. These studies further demonstrated the role of ecdysteroid titers in diapause, the phenology of summer and fall diapause, and the degree-day requirements for larval development and moth emergence. (Phoenix, AZ)

As part of a pilot test on pheromone trap calibration and mesoscale movement, data were collected on the temporal occurrence of corn earworm and tobacco budworm on corn and cotton. This research showed a consistent pattern in the species composition of eggs collected from cotton and a concentration of tobacco budworm associated with irrigated cotton. Corn earworm populations decreased dramatically during August, indicating the population was not producing successive generations in cotton. (College Station, TX; Stoneville, MS; Tifton, GA)

Significance

Progress in the areas of population dynamics and ecology have provided the basis of improved decision making capabilities, development and implementation of area wide control strategies, and development of adult control technology. Migration studies have elucidated the capabilities and mechanisms for long distance movement, and provide a basis for determining the impact of movement on regional population dynamics and its influence on area wide suppression programs.

Cooperators/Co-investigators

Lead ARS Scientists

Code	Name	SY	Location
RT	R. Teranishi	0.2	Albany, CA
KRB	K. R. Beerwinkle	0.9	College Station, TX
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JDL	J. D. Lopez	0.5	College Station, TX
TNS	T. N. Shaver	0.2	College Station, TX
JKW	J. K. Westbrook	0.8	College Station, TX
WWW	W. W. Wolf	1.0	College Station, TX
MHG	M. H. Greenstone	0.8	Columbia, MO
SKN	S. K. Narang	0.2	Fargo, ND
SDP	S. D. Pair	0.2	Lane, OK
RLO	R. L. Olsen	0.2	Mississippi State, MS
TLW	T. L. Wagner	0.3	Mississippi State, MS
JLW	J. L. Willers	0.4	Mississippi State, MS
ACB	A. C. Bartlett	0.2	Phoenix, AZ
DEH	D. E. Hendricks	0.8	Stoneville, MS
JRR	J. R. Raulston	0.5	Weslaco, TX

ARS Cooperators

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B. R. Wiseman	Tifton, GA

Non-ARS Scientists

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Research Gaps and Bottlenecks

1. Correlation of physiological mechanism with population processes,
2. Determination of the influence of pest control technology on population dynamics,
3. Aerial sampling of beneficial arthropods that affect Heliothis populations.

Research Constraints

Action Area 3 - Ecology and Population Dynamics

		Year 1	Year 2	Year 3	Year 4	Year 5
LEAD 3.1	Quantify pre-flight activities	Identify post-emergence preflight activity sites	Collect data	Collect data	Implement findings into development of adult control technologies	Continue as in yr 4
		JRR, PDL	SAME	SAME	SAME	SAME
SAFEGD 3.1.1	Optimize technology for observing pre-flight activities	Assess weaknesses/ strengths of existing nocturnal observation technologies	Identify, procure, and develop non-obtrusive procedures for making nocturnal observations	Collect data	Continue as in yr 3	Integrate findings into development of adult control technology
		PDL, JRR	SAME	SAME	SAME	SAME
OPTIM 3.1.2a	Determine influence of reproductive and feeding sites available to newly-emerged adult population	Determine influence of reproductively and non-reproductively attractive emergence sites	Determine influence of different host plant emergence sites	Determine influence of post-emergence feeding on preflight activity	Continue to collect data	Implement findings into adult control systems for different crops
		JRR, PDL	SAME	SAME	SAME	SAME
OPTIM 3.1.2b	Determine meteorological influences on newly-emerged adults	Identify meteorological parameters that influence post-emergence preflight behavior	Collect data	Continue as in yr 2	Integrate findings into adult control systems	--
		JKW	SAME	SAME	SAME	SAME
LEAD 3.2	Determine adult response to plants and plant volatiles	Develop procedures to qualify responses	Quantify responses	Determine meteorological factors affecting moth/plant interactions	Determine diffusion of volatiles from point sources affected by ambient atmospheric environment	Relate moth responses to diffusion coefficients
		PDL, JRR, TNS, JDL, RT, KRB, SDP, DEH, JKW	SAME	SAME	SAME	SAME
OPTIM 3.2.2	Determine and define interaction of adults with local plant populations	Develop and assess techniques	Identify and catalog plants that may be adult attractant sources	Collect data	Continue as in yr 3	Initiate the identification/ isolation of possible adult attractants
		PDL, JRR, TNS, JDL, RT, KRB, SDP	SAME	SAME	SAME	SAME

Action Area 3 - Ecology and Population Dynamics

		Year 1	Year 2	Year 3	Year 4	Year 5
LEAD 3.3	Determine migratory and trivial flight initiation and termination	Distinguish temporal differences between migratory and trivial flight	Correlate differences between migratory and trivial flight with adult physiological differences	Collect data	Continue as in yr 3	Integrate findings into assessments of impact of migration
		PDL, JRR, WWW, JKW, KRB, JDL, SDP	SAME	SAME	SAME	SAME
OPTIM 3.3.2	Develop equipment and technology for qualitative and quantitative behavioral observation of boundary layer flight	Assess existing technology and identify needs for new technology/ equipment	Develop/procure equipment	Collect data	Continue as in yr 3	Integrate findings into assessments of population dispersal
		PDL, WWW, JRR, KRB	SAME	SAME	SAME	SAME
SUPPL 3.3.3	Determine the influence of meteor-ological events on flight initiation and orientation	Identify meteorological events that affect flight initiation and orientation	Collect data	Determine the effects of meteorological events on flight initiation and orientation	Collect data	Integrate findings into assessments of migration and dispersal
		JKW	SAME	SAME	SAME	SAME
LEAD 3.4	Determine origins of adult populations	Establish procedures for overall study	Recruit cooperators	Collect data	Continue as in yr 3	Relate findings to determination of population origins
		JRR, PDL, WWW, JKW, JDL, SKN, DEH, ACB, SDP, KRB	SAME	SAME	SAME	SAME
SAFEGD 3.4.1	Develop regional SEM pollen reference libraries	Identify appropriate zones for pollen collections and recruit cooperators	Collect and identify pollens	Continue as in yr 2	Continue as in yr 3	Develop identification keys, collate, and publish data
		PDL, JRR	SAME	SAME	SAME	SAME

Action Area 3 - Ecology and Population Dynamics

		Year 1	Year 2	Year 3	Year 4	Year 5
OPTIM 3.4.2a	Identify and characterize source population zones	Establish procedures and develop cooperative efforts for study	Collect data	Continue as in yr 2	Integrate meteorological and radar information to determine population interactions between zones	Continue as in yr 4
		JRR, PDL, SKN, JKW, DEH, JDL	SAME	SAME	SAME	SAME
OPTIM 3.4.2b	Utilize standardized sampling procedures in multiple cropping systems across geographical regions to determine chronology of developing populations	Identify ecological zones and cooperators for studies	Collect data using developed standardized procedures	Continue as in yr 2	Continue as in yr 3	Integrate meteorological and radar findings with ecological data to develop migration models
		JRR, JDL, PDL, SDP	SAME	SAME	SAME	SAME
OPTIM 3.4.2c	Determine regions in Mexico that may influence development of U.S. populations in the spring	Identify cooperators and establish trapping systems across Mexico	Determine chronology of cropped and non-cropped hosts at trapping locations that produce populations	Collect data	Continue as in yr 3	Integrate findings with U.S. ecological studies to determine impact of populations developing in Mexico
		JRR, PDL, JDL	SAME	SAME	SAME	SAME
OPTIM 3.4.2d	Analyze genetic variation in natural populations	Determine appropriate technology for testing and recruit cooperators	Assess technology and collect data	Collect data	Continue as in yr 3	Integrate findings into improving control strategies
		SKN	SAME	SAME	SAME	SAME
OPTIM 3.4.2e	Determine pollen loads on adults to determine possible origin	Identify cooperators and select ecological zones for study	Collect data	Continue as in yr 2	Continue as in yr 3	Correlate findings to feeding and migratory behavior
		PDL, JRR	SAME	SAME	SAME	SAME
SUPPL 3.4.3a	Develop DNA and cuticular hydrocarbon analyses	Assess preliminary information to select appropriate technology	Refine technology	Assess feasibility of determining population differences	Collect data	Continue as in yr 4
		SKN	SAME	SAME	SAME	SAME

Action Area 3 - Ecology and Population Dynamics

		Year 1	Year 2	Year 3	Year 4	Year 5
SUPPL 3.4.3b	Develop efficient marking techniques for tracing moth population origin	Identify possible marking materials JRR, JDL, TNS	Develop techniques for non-obtrusive marking of large natural populations SAME	Assess effects of marks on moth behavior SAME	Collect data SAME	Apply developed marking systems to populations of adults for dispersal studies SAME
LEAD 3.5	Determine impact of migrant populations in recipient regions	Establish standard procedures for studying populations with different ecological zones JRR, PDL, JDL, SDP, JKW	Collect data to determine synchrony of chronological events among populations and regions SAME	Develop technology to validate the movement of populations between regions and collect data SAME	Collect data SAME	Use population models to assess impact of immigrants SAME
OPTIM 3.5.2	Determine spatial and temporal patterns of populations	Develop capabilities for estimating population density, including survivorship curves JRR, PDL, JDL, SDP, TLW, JLW	Determine biotic and abiotic factors that affect survivorship SAME	Collect data in different ecosystems SAME	Continue as in yr 3 SAME	Integrate findings into population models SAME
LEAD 3.6	Migration technology	Develop equipment for automating radar data collection WWW, KRB, JKW	Assess and develop equipment for electronic identification of species undergoing migratory flight SAME	Refine equipment and collect data SAME	Refine equipment and collect data SAME	Integrate equipment and findings for refining existing migration research studies SAME
SAFEGD 3.6.1	Assess feasibility of doppler radar systems for migration research	Conduct feasibility study WWW	Procure and refine equipment SAME	Develop data collection procedures SAME	Refine system and collect data SAME	Refine system, collect data, and relate findings to dispersal and migratory activities SAME
OPTIM 3.6.2a	Characterize dispersal attributes of moth clouds arising from source areas	Assess current technology and design approaches JKW, WWW, PDL, JRR, KRB	Coordinate meteorological, ecological, behavioral and radar technology for studying cloud dispersal and fallout SAME	Collect data and refine technology SAME	Continue as in yr 3 SAME	Develop cloud dispersal models and relate to impact of migratory activities SAME

Action Area 3 - Ecology and Population Dynamics

		Year 1	Year 2	Year 3	Year 4	Year 5
OPTIM 3.6.2b	Develop and improve aerial sampling technology	Develop equipment for collecting intact specimens	Assess the influence of collection system on moth avoidance reactions	Refine equipment and collect data	Continue as in yr 3	Collect intact specimens and conduct comparative physiological studies
		KRB	SAME	SAME	SAME	SAME
SUPPL 3.6.3a	Correlate meteorological parameters with insect transport during migration	Identify and assess equipment needs	Procure equipment and plan coordinated data collection	Measure long-distance atmospheric trajectories and dispersion	Continue data collection	Integrate findings into migration model
		JKW, WWW, KRB	SAME	SAME	SAME	SAME
SUPPL 3.6.3b	Develop climatological phenological atlas defining insect source areas	Analyze and map major host plant zones	Overlay zones with climatological data	Assess meteorological interactions between zones producing moths available for transport	Conduct ecological, meteorological and radar studies to validate interzone movement	Continue study and integrate findings into migration model
		JKW, PDL, JRR	SAME	SAME	SAME	SAME
LEAD 3.7	Optimize rbWHIMS model for cotton production and protection	Identify structure and function of enhanced model	Research, develop, implement, and test system components	Continue as in yr 2	Continue as in yr 3	Continue as in yr 4
		TLW, RLO, JLW	SAME	SAME	SAME	SAME
SAFEGD 3.7.1a	Expand geographical application of rbWHIMS	Recruit cooperators	Obtain and evaluate data	Formulate rules and methods	Encode, verify, and document	Implement and test
		TLW, RLO, JLW	SAME	SAME	SAME	SAME
SAFEGD 3.7.1b	Develop and integrate methods into WHIMS to deal with management uncertainties	Identify and evaluate system constraints	Formulate system design	Develop prototype model	Verify and test	Continue as in yr 4
		TLW, RLO, JLW	SAME	SAME	SAME	SAME
OPTIM 3.7.2a	Expand rbWHIMS to include all cotton pests in Mid-south	Obtain and evaluate data	Formulate rules and methods	Encode, verify and document	Implement and test	Continue as in yr 4
		TLW, RLO, JLW	SAME	SAME	SAME	SAME

Action Area 3 - Ecology and Population Dynamics

		Year 1	Year 2	Year 3	Year 4	Year 5
OPTIM 3.7.2b	Design and implement WHIMS features to include multiple pest-species interactions	Identify cooperators	Identify and evaluate system constraints, formulate system design and methodology	Collect, evaluate and integrate information into prototype model	Verify and test	Continue as in yr 4
		TLW, RLO, JLW	SAME	SAME	SAME	SAME
LEAD 3.8	Integrate WHIMS and GOSSYM/COMAX	Develop capabilities to use GOSSYM input and output values in WHIMS	Develop WHIMS to predict impact of insect on host	Continue as in yr 2	Continue as in yr 3	Develop capabilities to use WHIMS input and output in GOSSYM
		TLW, RLO, JLW	SAME	SAME	SAME	SAME
OPTIM 3.8.2	Develop and integrate a geographic information system	Obtain resources for developing system	Identify and evaluate system design and constraints	Develop prototype, verify, and test	Continue as in yr 3	Proceed with full system development
		TLW, RLD, JLW	SAME	SAME	SAME	SAME
LEAD 3.9	Develop optimum sampling procedures	Design alternative sampling protocols	Collect data	Continue as in yr 2	Continue as in yr 3	Evaluate
		TLW, RLO, JLW	SAME	SAME	SAME	SAME
		JRR, PDL, JDL, SDP, JKW	SAME	SAME	SAME	SAME
SAFEGD 3.9.1a	Improve capabilities of estimating pest abundance from limited sample data	Adapt sampling techniques for multiple pest species	Collect data	Continue as in yr 2	Continue as in yr 3	Integrate findings into pest management technology
		TLW, RLO, JLW	SAME	SAME	SAME	SAME
SAFEGD 3.9.1b	Develop method to differentiate eggs and small larvae of *H. virescens* and *H. zea*	Determine immunological differences between species	Continue as in yr 1	Develop procedures for using technology under field conditions	Continue as in yr 3	Transfer technology for field use
		MHG	SAME	SAME	SAME	SAME
OPTIM 3.9.2	Refine sampling data sets using Bayesian statistical concepts	Adapt statistical procedures for analyzing sampling data	Develop models for evaluating statistical approach	Refine techniques	--	--
		TLW, RLO, JLW	SAME	SAME	SAME	SAME

Action Area 4 - Behavior Modifying Chemicals

Introduction

At least four long-range critical research needs have been identified. These are:

Develop and implement methods for using kairomonal compounds derived from plants to suppress Heliothis/Helicoverpa populations in cropping situations via direct control of adults or indirectly through control of oviposition;

Develop and implement methods for suppression of Heliothis/Helicoverpa populations using: a) sex attractant pheromones to disrupt mating via permeation of the atmosphere; b) combinations of pheromones, plant-derived kairomones, and toxicants to kill adults; and/or c) attracticide baits in traps to provide improved methods for forecasting and predicting Heliothis/Helicoverpa populations;

Suppress Heliothis/Helicoverpa via interference with pheromone biosynthesis, neuroendocrine, and olfactory systems; and

Develop and implement methods to use semiochemicals to enhance performance of insect parasitoids as economically effective and reliable control agents in management strategies for Heliothis/Helicoverpa species.

These critical needs are extremely diverse, and progress or the lack thereof in any one of these areas will not necessarily affect progress in any of the other elements. However, certain of these critical research needs are closely allied with other Action Areas and probably should be included, at least in part, with these other areas.

Major Accomplishments

Over the past five years, interest in kairomonal compounds from plants that affect attraction and oviposition behavior of Heliothis/Helicoverpa has become intensified greatly. Recent results indicate that volatiles emitted by plants are used by Heliothis/Helicoverpa to locate feeding and oviposition sites. Isolation and identification of these chemicals is in progress at several locations in ARS. Compounds that affect attraction and oviposition behavior have been isolated and identified from several cultivated hosts including cotton (Gainesville, FL; Albany, CA), corn (Albany, CA; College Station, TX; Tifton, GA; Athens, GA), tobacco (Gainesville, FL; Tifton, GA; Athens, GA; Oxford, NC), alfalfa (Albany, CA), and red clover (Albany, CA), and from wild hosts such as guar (College Station, TX; Weslaco, TX) and beggar's tick (Gainesville, FL). Laboratory and field bioassays have been developed to support identification of kairomonal components that attract moths to plants to feed (Gainesville, FL; Albany, CA; College Station, TX; Weslaco, TX) and oviposit (Gainesville, FL; Tifton GA; Athens, GA; Oxford NC), and also to measure possible negative effects on attraction and oviposition behavior (Gainesville, FL). Plant kairomones present numerous opportunities to manipulate and manage Heliothis/Helicoverpa populations

via direct control measures or indirectly through improved methods for detection, monitoring, and prediction.

Female-produced pheromones have been identified for H. zea (Beltsville, MD) and H. virescens (Gainesville, FL; Beltsville, MD), and pheromone-related behavior has been investigated in the laboratory (Gainesville, FL; Tifton, GA; Belstville, MD). Considerable research also has been conducted on pheromone dispensing systems and trap designs for surveying Heliothis/Helicoverpa populations (Gainesville, FL; College Station, TX; Tifton, GA; Beltsville, MD; Stoneville, MS). Some progress has been achieved for both species in relating captures of male moths in traps to numbers of adult moths collected in fields at night (College Station, TX; Tifton, GA; Stoneville, MS; Weslaco, TX), and to numbers emerged in spring (College Station, TX; Tifton, GA; Stoneville, MS, Weslaco, TX) and to rates of oviposition on crops (Gainesville, FL; College Station, TX; Tifton, GA; Stoneville, MS; Weslaco, TX).

In wind tunnel studies and field experiments, (Z)-11-hexadecenal was shown to disrupt effectively Heliothis/Helicoverpa sexual communication when evaporated at high dosages relative to the level released by an individual female moth (Gainesville, FL). Observations indicate that the most effective mechanism of mating disruption appears to be trail masking (Gainesville, FL). Recent improvements in formulation technology suggest that mating disruption could become a viable adjunct to the present control strategy for Heliothis/Helicoverpa (Gainesville, FL).

Investigations of Heliothis/Helicoverpa pheromone biosynthesis in the last five years have resulted in the discovery of a peptide produced in the brain that turns on pheromone biosynthesis, a factor produced in the bursae of aging virgin females that suppresses pheromone biosynthesis, factors produced by males and transferred to females during mating that suppress pheromone biosynthesis, and esterases, primary alcohol oxidases, and other enzymes that regulate various steps in the pheromone biosynthesis pathway (Gainesville, FL; Beltsville, MD). The potential exists to develop agonists or antagonists for any or all of the various factors involved in this critical process. Also, it may be possible to alter or manipulate these systems via genetic engineering. Any development of a practical method to alter or shut down pheromone biosynthesis in Heliothis/Helicoverpa species would be extremely valuable for control of these pests.

The ability of parasites and predators to control Heliothis/Helicoverpa populations under certain conditions has been established. However, this method of biological control cannot be relied upon to work consistently. Additionally, this method is not always effective at low host population densities when it would have the greatest impact. One of the factors that greatly influences the effectiveness of parasites and predators is their ability and motivation to locate their hosts. Evidence strongly indicates that the host foraging behavior of beneficial insects is regulated by semiochemicals and that these insects can be conditioned to search for a particular host on a particular plant at a time when they would have the greatest impact (Gainesville, FL; Tifton, GA; Stoneville, MS).

Significance

The role of sex pheromones in the reproductive biology of Heliothis/Helicoverpa spp. is widely acknowledged, if not yet fully understood. Recent research also has shown that other semiochemicals, especially plant-derived kairomones, are significant factors in the feeding and reproductive behaviors of the Heliothis/Helicoverpa complex and their parasitoids. This area has engendered considerable interest of late with females of the species being the principal target. Thus, pheromones and other semiochemicals--especially plant kairomones--offer extraordinary potential for management of the Heliothis/Helicoverpa complex on a variety of crops. If the development of pheromone technology over the past 30 years is any indication of the progress that might be expected in the area of behavior-modifying plant chemicals, then the future indeed looks bright for the development of new and innovative approaches for management of Heliothis/Helicoverpa spp. with semiochemical-based technology.

Cooperators/Co-investigators

Lead ARS Scientists

Code	Name	SY	Location
SK	S. Kint	0.5	Albany, CA
DML	D. M. Light	0.5	Albany, CA
RT	R. Teranishi	0.5	Albany, CA
WSS	W. S. Schlotzhauer	0.1	Athens, GA
RFS	R. F. Severson	0.6	Athens, GA
MES	M. E. Snook	0.1	Athens, GA
AKR	A. K. Raina	1.0	Beltsville, MD
KRB	K. R. Beerwinkle	0.1	College Station, TX
PDL	P. D. Lingren	0.5	College Station, TX
JDL	J. D. Lopez	0.5	College Station, TX
TNS	T. N. Shaver	0.8	College Station, TX
JKW	J. K. Westbrook	0.2	College Station, TX
RED	R. E. Doolittle	0.1	Gainesville, FL
RRH	R. R. Heath	0.2	Gainesville, FL
MSM	M. S. Mayer	0.1	Gainesville, FL
JRM	J. R. McLaughlin	0.3	Gainesville, FL
ERM	E. R. Mitchell	0.3	Gainesville, FL
PEAT	P. E. A. Teal	0.8	Gainesville, FL
FCT	F. C. Tingle	0.8	Gainesville, FL
JHT	J. H. Tumlinson	0.2	Gainesville, FL
SDP	S. D. Pair	0.1	Lane, OK
DMJ	D. M. Jackson	0.4	Oxford, NC
DEH	D. E. Hendricks	0.2	Stoneville, MS
HRG	H. R. Gross	0.1	Tifton, GA
WJL	W. J. Lewis	0.3	Tifton, GA
JRR	J. R. Raulston	0.2	Weslaco, TX
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Albert W. Johnson	Clemson Univ.	Florence, SC
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Gary A. Herzog	Univ. of Georgia	Tifton, GA
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J. C. van Lenteran	Agric. Univ.	Wageningen, The Netherlands

Research Gaps and Bottlenecks

Application technology is an important component of several lead arrays. Engineering and formulation experts should be consulted in the early stages of development of these programs.

Semiochemicals that may affect larval feeding and development (e.g., stimulants, deterrents, growth regulators) are not considered in the proposed action plan. This is a potentially useful adjunct to future area-wide management schemes for Heliothis/Helicoverpa.

Other gaps noted in the plan include:

1. Physiology, biochemistry, and biosynthesis of active compounds in plants;
2. Trap crop technology; and
3. Acoustic responses in the presence of behavior modifying chemicals.

The following issues cannot be defined as gaps per se because some scientists already may have considered them in their research plans.

1. Studies may be directed towards changing the insect's behavior as to habitat. Chemicals might be used to reverse an insect's cue to leave a non-suitable host (such as dry corn) to seek a more suitable environment; thus, keeping the insect in a non-suitable environment.

2. Potential pesticides such as IGRs, microorganisms, nematodes, etc., may be used with attractants instead of conventional insecticides.

3. The feasibility and compatibility of combinations of attractants and pesticides should be studied to seek a 'common' method of control for several pests simultaneously, e.g., tobacco budworm, corn earworm, boll weevil, pink bollworm.

Action Area 4 - Behavior Modifying Chemicals

		Year 1	Year 2	Year 3	Year 4	Year 5
Monitoring and Managing Populations with Semiochemicals						
LEAD 4.1	Develop and implement methods to manage *Heliothis*/*Helicoverpa* populations in cropping systems with plant derived allelochemicals	Isolate and identify oviposition attractants, stimulants, and deterrents	Continue as in yr 1; conduct laboratory and field cage bioassays of isolated oviposition attractants, stimulants, and deterrents	Synthesize and formulate effective candidate compounds; evaluate attractants and/or oviposition stimulants, alone and in combination with pheromones; evaluate oviposition deterrents in small plot field trials	Continue as in yr 3; increase size of field plots. Investigate possible effects of oviposition attractants, stimulants, and deterrents on parasitoid populations and secondary insect pests	Conduct tests in large field plots to evaluate efficacy of oviposition deterrents when used alone, and in combination with conventional pesticides. Continue evaluating possible effects on oviposition and secondary insect pests
		HRG, RFS, DMJ, FCT, RRH, ERM, DML, JKW, SDP	SAME	SAME	HRG, DMJ, FCT, ERM, JKW, SDP,	DMJ, FCT, ERM, JKW, SDP
SAFEGD 4.1.1	Develop oviposition attractants and stimulants as tools for monitoring *Heliothis*/*Helicoverpa*	Develop assay procedures	Test biologically active isolates	Continue as in yr 3	Continue testing as in yrs 2 and 3	Compare with conventional monitoring methods
		DEH, RFS, DMJ, FCT, ERM, DML	DEH, DMJ, FCT, ERM, DML, RFS	SAME	SAME	SAME
OPTIM 4.1.2	Combine oviposition attractants with sex pheromone to monitor and/or manage both sexes	Isolate and identify oviposition attractants	Continue testing as in yr 1	Test attractant formulations	Test attractant/ pheromone combinations	Optimize formulation and trap design
		FCT, RRH, ERM, DML	SAME	SAME	SAME	SAME
SUPPL 4.1.3	Develop methods to determine whether allelochemicals of plant origin work in concert with plant source radiation to attract *Heliothis*/ *Helicoverpa*	Develop methods to measure responses of *Heliothis*/*Helicoverpa* to plant source radiation	Continue as in yr 1	Continue as in yr 2	Test response to plant attractants and irradiation	Continue testing

Action Area 4 - Behavior Modifying Chemicals

		Year 1	Year 2	Year 3	Year 4	Year 5
LEAD 4.2	Develop and implement methods to suppress Heliothis/Helicoverpa populations with attracticide (allelochemical) baits for adults	Isolate plant kairomones that attract adults to feed	Continue as in yr 1; begin identification of active chemicals	Synthesize and develop bait formulations for use in attracticide applications	Continue as in yr 3; begin EUP clearance	Conduct field trials to evaluate effectiveness and economic feasibility of the attracticide concept for controlling Heliothis/Helicoverpa populations; continue EUP clearance
		RFS, DMJ, FCT, PDL, TNS, RRH, ERM, MSM, DML, SDP, SK, JKW, RFS, JRR	DMJ, FCT, PDL, TNS, RRH, ERM, DML, RFS, JKW, SDP, JRR	DMJ, JKW, PDL, JDL, TNS, KRB, RRH, ERM, SDP, RFS, JRR	SAME	DMJ, JKW, PDL, JDL, TNS, KRB, JRR
SAFEGD 4.2.1	Determine whether plant-derived kairomone attractants enhance the efficiency of pheromone traps for capturing Heliothis/ Helicoverpa	--	Develop field bioassay	Test combinant formulations	Continue testing as in yr 3	Identify best combinant formulation and transfer technology
			FCT, ERM, DML, JKW	SAME	SAME	ERM, DML, JKW
OPTIM 4.2.2a	Select effective chemical toxicant and formulation for adults that do not interfere with the efficiency of the attractant	Laboratory testing of toxicants	Determine strategies for toxicant/bait formulations	Evaluate toxicant/bait formulations in the laboratory; initiate EUP clearance	Field testing of formulations; continue EUP clearance	Complete studies and integrate with field tests; continue EUP clearance
		DEH, FCT, PDL, JDL, ERM, JKW, JRR, DAW	DEH, PDL, JDL, TNS, ERM, JKW, JRR, DAW	DEH, FCT, PDL, JDL, TNS, JKW, JRR, DAW	DEH, JKW, PDL, JDL, TNS, KRB, ERM, JRR, DAW	SAME
OPTIM 4.2.2b	Develop lab bioassay protocol for testing phytoattractants	Design ofactometer and determine optimum physical and biological operating parameters	Continue as in yr 1 and test attractants	Test attractants and attracticides	Test attractants and attracticides	Test attracticides
		JRR, ERM, FCT	SAME	SAME	SAME	SAME
SUPPL 4.2.3	Evaluate attractancy of Heliothis/ Helicoverpa to non-plant synthetic chemicals	Preliminary screening of candidate chemicals	Continue screening	Continue screening and integrate active compounds with Lead Array 4.2	--	--
		FCT, MSM	SAME	SAME		

Action Area 4 - Behavior Modifying Chemicals

		Year 1	Year 2	Year 3	Year 4	Year 5
LEAD 4.3	Develop and implement methods to use pheromone mating disruption as an economically effective and reliable strategy for managing Heliothis/Helicoverpa species	Establish research plots and begin evaluating various pheromone blends and formulations DEH, JRM, ERM, MSM, DML	Continue evaluations, incorporating changes from yr 1 SAME	Continue as in yr 2, and establish larger plots SAME	Evaluate in large blocks with emphasis on tracking the year-to-year effects on Heliothis/Helicoverpa SAME	Evaluate temporal and spatial effects of mating disruption control strategy SAME
SAFEGD 4.3.1	Compare the distribution of Heliothis/Helicoverpa and non-target species in pheromone-treated areas	-- DEH	-- SAME	Establish species profile of insects inhabiting test fields DEH, FCT	Identify non-target species that are impacted by Heliothis/Helicoverpa pheromones SAME	Continue study of effects on non-target species SAME
OPTIM 4.3.2	Develop mechanized methods compatible with grower operations for distributing pheromone formulations	-- DEH	-- SAME	Obtain information necessary for securing experimental use permit SAME	-- SAME	-- SAME
SUPPL 4.3.3	Evaluate selected non-pheromone chemicals as potential mating disruptants	Preliminary screening of candidate chemicals DEH, JRM, ERM, MSM, DML	Formulate most promising candidates and incorporate into Lead Array 4.3 SAME	--	--	--
LEAD 4.4	Develop and implement methods for using semiochemicals to improve estimates of Heliothis/Helicoverpa populations and detect exotic species	Evaluate blends and formulations of sex attractant pheromones and other chemical attractants for trapping efficacy of males and females in field settings AKR, DEH, DMJ, FCT, JRM, PDL, JDL, TNS, KRB, ERM, MSM, DML	Continue evaluations, incorporating changes from yr 1 SAME	Initiate area-wide surveys and infield monitoring of Heliothis/Helicoverpa populations using most effective attractant combinations. Attempt to correlate moth captures in traps with infield populations AKR, DEH, PDL, JDL, FCT, TNS, KRB, ERM, DMJ	Continue as in yr 3; begin developing model systems as predictive tools for long-range and inter-field movement by Heliothis/Helicoverpa DEH, DMJ, PDL, JDL TNS, KRB	Continue as in yr 4; refine model systems to user-friendly status DEH, DMJ

Action Area 4 - Behavior Modifying Chemicals

		Year 1	Year 2	Year 3	Year 4	Year 5
SAFEGD 4.4.1	Determine attractiveness of allelochemicals to other economic lepidopterous pests	Preliminary screening of candidate chemicals	Continue as in yr 1	Evaluate active materials in different cropping systems	Combine active material with pheromone of responding species and test in the field	Attempt to correlate moth captures to in-field populations
		DMJ, JRM, PDL, JDL, TNS, KRB, ERM, DML, RFS, JKW, JRR	SAME	JRM, PDL, JDL, TNS, KRB, ERM, DML, JKW, JRR	JRM, ERM, DML, JKW	PDL, JDL, TNS, KRB, ERM, JKW, JRR
OPTIM 4.4.2	Develop effective trapping systems	Evaluate commercially available traps	Modify traps as needed	Determine most effective trap placement	Continue and integrate results with Lead Array 4.4	Continue as in yr 4
		DEH, DMJ, PDL, JDL, KRB, ERM	SAME	SAME	SAME	SAME
SUPPL 4.4.3	Determine if plant kairomones can be used to habituate Heliothis/Helicoverpa	Develop techniques for measuring habituation	Continue as in yr 1	Field testing of candidate formulations	Continue as in yr 3	Field testing in large field plots
		ERM, DML	SAME	SAME	SAME	SAME
Suppression of Populations via Interface with Pheromone Biosynthesis						
LEAD 4.5	Develop methods to interfere with neuro-endocrine control of pheromone biosynthesis in Heliothis/Helicoverpa species	Identify neural/hormonal factors that regulate pheromone biosynthesis	Elucidate mechanism of action and receptors for factors regulating pheromone biosynthesis; conduct structure activity studies	Continue as in yr 2; identify antagonists for regulatory factors that will block pheromone production; begin identification and cloning of genes for regulatory factors	Continue as in yr 3; develop delivery systems for peptides and other factors and/or antagonists; develop methods to express genes for regulatory factors in baculovirus	Conduct tests to evaluate effectiveness of various factors and delivery systems in suppressing pheromone production in Heliothis/Helicoverpa species
		AKR, PEAT, JHT	SAME	SAME	AKR, PEAT	AKR, PEAT, JHT

Action Area 4 - Behavior Modifying Chemicals

		Year 1	Year 2	Year 3	Year 4	Year 5
SAFEGD 4.5.1	Screen compounds including biogenic amines and other peptides that have been identified from insects and shown to have physiological activity for their effects on pheromone biosynthesis	Develop physiological bioassay to measure effects of selected compounds on pheromone biosynthesis PEAT	Select and screen candidate compounds from activity in suppressing or enhancing pheromone biosynthesis SAME	Continue as in yr 2 SAME	Develop methods to apply active compounds to insects in natural situations PEAT, JHT	Field test active compounds SAME
OPTIM 4.5.2	Develop practical methods to apply neuropeptides, biogenic amines, and other identified active substances to insects to interfere with or manipulate pheromone biosynthesis	Determine stability and compatibility of active compounds AKR, PEAT, JHT	Continue as in yr 1, and determine most effective combinations, blends, etc., to interfere with or manipulate pheromone biosynthesis SAME	Develop formulations for most effective compounds or blends of compounds SAME	Laboratory and small scale evaluations of formulated compounds SAME	Field test best formulations SAME
SUPPL 4.5.3	Investigate factors in the environment, including plant-produced substances that may educt the regulating of pheromone production via interfering with or inducing the action of neuropeptides and other endogenous factors	Screen host plants and other substances from natural habitats of Heliothis/Helicoverpa species to find substances that enhance or suppress pheromone production AKR, DEH, PEAT, JHT	Isolate and Identify active factors AKR, PEAT, JHT	Synthesize active chemical compounds AKR, RED	Formulate active synthetic compounds and conduct small-scale tests AKR, DEH, PEAT, JHT	Field test active factors AKR, PEAT, JHT
LEAD 4.6	Develop methods to disrupt the enzymatic systems in the pheromone biosynthetic pathway to suppress pheromone production	Isolate/characterize enzymes controlling biosynthesis PEAT, JHT	Continue as in yr 1; begin development of antagonists for enzyme systems SAME	Continue development of antagonists for enzyme systems; begin development of methods for delivery of antagonists SAME	Complete development of antagonists and delivery systems SAME	Evaluate antagonists and delivery systems for effectiveness in suppressing pheromone production in Heliothis/Helicoverpa species SAME

Action Area 4 - Behavior Modifying Chemicals

		Year 1	Year 2	Year 3	Year 4	Year 5
SAFEGD 4.6.1	Screen enzyme inhibitors and blockers of oxidase and esterases for compounds that may block pheromone biosynthesis	Develop physiological and biochemical assays PEAT, JHT	Select and screen candidate compounds SAME	Continue as in yr 2 SAME	Develop methods to apply active compounds SAME	Evaluate active compounds for practical value in insect control SAME
OPTIM 4.6.2	Develop practical methods to apply or deliver enzyme inhibitors, antagonists or agonists for for control of pheromone production	Determine stability and compatibility of active compounds AKR, PEAT, JHT	Determine most effective compounds or blends of compounds SAME	Develop formulations for most effective compounds SAME	Develop methods to apply formulated compounds SAME	Evaluate formulated compounds for effectiveness in laboratory and field SAME
SUPPL 4.6.3	Investigate plant substances and other factors in the environment that may enhance or inhibit pheromone production through their effects on the biosynthetic pathway	Screen host plants and other substances from natural habitats of Heliothis/Helicoverpa species to find substances that enhance or suppress pheromone production DEH, PEAT, JHT, DML	Isolate and identify active factors PEAT, JHT, DML	Synthesize active chemical compounds RED, DML, RT	Formulate active synthetic compounds and conduct small scale tests DEH, PEAT, JHT, DML	Field test active factors SAME
Semiochemical Enhancement of Parasitoid Efficiency						
LEAD 4.7	Develop and implement strategies for using semiochemical-enhanced parasitoids to achieve economical, effective and reliable biological control of Heliothis/Helicoverpa	Identify key semiochemicals involved in parasitoid foraging; develop effective bioassays to evaluate the effect of semiochemicals in the lab and field JHT, WJL, RFS	Develop methods to apply semiochemicals for conditioning parasitoids before release; develop effective semiochemical formulations for use in field tests; develop small-scale field test evaluation methods SAME	Conduct small-scale field plot tests to evaluate procedures for applying formulated semiochemicals and determining their effectiveness WJL	Continue as in yr 3, and increase the size of the field plots SAME	Evaluate methods for using semiochemicals to condition, retain and enhance the effectiveness of parasitoids released against Heliothis/Helicoverpa species JHT, WJL

Action Area 4 - Behavior Modifying Chemicals

		Year 1	Year 2	Year 3	Year 4	Year 5
SAFEGD 4.7.1	Develop methods for using semiochemicals to survey parasitoid populations	Design wind tunnel assay to measure the response of parasitoids to semiochemicals placed within conventional insect survey traps	Select or design traps having maximum efficiency for monitoring parasitoids	Field evaluate semiochemical formulations	Determine optimum distribution of semiochemical baited traps	Relate number of parasitoids captured in semiochemical baited traps to rates of host parasitization in targeted crop
		DMJ, FCT, JHT, WJL	DMJ, FCT, WJL	FCT, JHT, WJL	SAME	FCT, WJL
OPTIM 4.7.2	Determine the effect of intrinsic factors on parasitoid dispersal and foraging behavior	Identify primary environmental variables that influence the dispersal, efficiency, and longevity of parasitoids	Continue as in yr 1	Measure the ability of select stimuli to retain parasitoids within targeted fields	Measure the ability of select stimuli to improve foraging efficiency	Incorporate influential stimuli into augmentation release programs with parasitoids of Heliothis/Helicoverpa
		DMJ, WJL	SAME	DMJ, JHT, WJL	SAME	JHT, WJL
SUPPL 4.7.3	Determine the effect of learning on parasitoid searching efficiency	Determine which chemical cues are learned and how learning is affected by other intrinsic factors	Determine when and how learning occurs	Determine how rearing, transport and release strategies impact learning	Develop procedures to enhance and monitor learning during rearing and release	Implement positive learned behaviors into rearing and release programs
		JHT, WJL	SAME	WJL	SAME	SAME

Action Area 5 - Biological Control

Introduction

Helicoverpa zea and Heliothis virescens, as a complex, are the most costly agricultural insect pests in the United States. They attack a wide range of crops and other plants and cause economic losses estimated to exceed $1 billion annually (USDA 1976). Further, the extensive frequent use of conventional pesticides for their control presents serious environmental consequences. The need for effective and environmentally safe control technology is urgent. Recent findings regarding the contamination of ground water with pesticides, together with emerging resistance problems for the limited remaining number of effective pesticides, has greatly intensified this urgency.

In field crops, augmentation is an important part of biocontrol of pests. Augmentation of entomophagous insects is considered among, if not the leading, viable alternative to conventional pesticides. However, the lack of critical biological information and methodology are barriers to their use for control of many of our most serious agricultural pests. A major research thrust to include field evaluation is imperative to developing this important technology.

Major Accomplishments

Demonstrated increases in effectiveness of Bacillus thuringiensis in field control through development of new isolates, additives, and formulations. (Oxford, NC; Stoneville, MS; Tifton, GA)

Broad spectrum nuclear polyhedrosis virus having infectivity to both bollworm and budworm was recently isolated. (Columbia, MO; Fresno, CA; Stoneville, MS; Phoenix, AZ)

Increased in vitro production of polyhedral inclusion bodies has been accomplished through development of new lepidopteran cell lines. (Columbia, MO)

Cage and field studies demonstrated potential efficacious use of baculovirus in reducing adult bollworm and budworm emergence early-season, providing the basis for a 100 sq mi area pilot test. (Stoneville, MS; Sandoz)

Demonstrated increase in infectivity and environmental persistence of baculovirus through the use of various additives or alkaline treatment; demonstrated that an NPV was genetically stable over a 20-yr period by propagation in insects. (Columbia, MO; Tifton, GA)

Discovered nonoccluded baculovirus that reduces vigor of M. croceipes (Tifton); demonstrated that a venom from an ectoparasite arrested molting in Heliothis/Helicoverpa and numerous other lepidopteran species (Columbia); developed genetic information for parasite population survey and for detecting resistance (Columbia). First PCR studies show that a molecular genetic difference can be found between male and female Microplitis croceipes (Fargo, ND; Columbia, MO). A dominant black-body

mutant marker of M. croceipes is available for parasite population studies. (Columbia, MO)

Evaluation of new Bt strains, formulations, and application methods on tobacco. Field evaluations (1988-91) of an NPV-autodissemination technique for suppression of H. virescens in tobacco and H. zea in sweet corn; low levels (significant) of control were demonstrated in both cropping systems. (Oxford, NC)

Developed efficient methodology for mass producing Archytas marmoratus on greater wax moth (Tifton, GA); mechanized mass production procedures have been developed for Heliothis virescens and its sterile hybrid backcross, and for Helicoverpa zea (Mississippi State, MS); these are used for in vivo production of Microplitis croceipes and commercial level production of NPV. (Mississippi State)

Improved culture media for egg hatch and viability of Trichogramma and Chrysoperla; in vitro culture of E. bryani is promising for large-scale production (Kentucky, Weslaco, TX); a cell line already mass-produced for baculovirus production can be used to support growth and development of M. croceipes embryos in vitro (Gainesville, FL; Beltsville, MD); an artificial oviposition substrate was developed for M. croceipes (Gainesville, FL); molting of M. croceipes larvae is independent of host hormones, but is dependent on a minimum critical parasitoid larval size (Gainesville, FL); M. croceipes growth in vitro is dramatically improved by the presence of teratocytes. (Gainesville, FL; Lexington, KY)

Field application of Steinernema sp. resulted in high mortality of Helicoverpa (Weslaco, TX). Developed a species- and instar-specific ELISA for remains of H. zea fifth instars in predators stomachs (this has been tested with spiders, stink bugs, and polistine wasps); adapted a new immunoassay format, Immunodat, for predator stomach analysis which may be used in foreign exploration for predators (Columbia, MO). Demonstrated virulence of entomopathogenic fungi (e.g., Nomuraea rileyi) in Heliothis/Helicoverpa due to complex profile of chitin-degrading enzymes (Columbia, MO).

Insecticides applied to parasitized budworm larvae and to adult M. croceipes showed that parasitoids tolerated certain compounds more than others (Columbia, MO; Stoneville, MS).

Females of M. croceipes respond to volatile cues from host plants in combination with a non-volatile host recognition kairomone (Gainesville, FL; Tifton, GA); elucidated semiochemical mediated foraging behavior in M. croceipes and Cotesia marginiventris (Gainesville, FL; Tifton, GA); experience and learning were found to play a key role in host foraging in both species (Gainesville, FL; Tifton, GA).

Established mechanized production procedures with current equipment to produce H. virescens, H. zea, and Heliothis backcross to evaluate proposed biological control concepts (Mississippi State, MS). Mass rearing of the predator Geocoris punctipes has been enabled by development of a low cost artificial medium and rearing method. This is being utilized by APHIS-S&T toward allowing augmentative releases of

Geocoris (Phoenix, AZ). Progress is being made in improving mass propagation technology for Chrysoperla (Weslaco, TX).

Use of an imported eriophyid mite for the control of Geranium dissectum, a major host of first generation Heliothis/Helicoverpa spp. (Stoneville, MS).

Insecticides applied to Heliothis virescens that were parasitized by M. croceipes and to adult wasps show that certain compounds favor survival of the parasitoid. This information would be important in integrating biological control into pest management strategies (Stoneville, MS).

Significance

Mass rearing technology for Heliothis/Helicoverpa spp. is advanced and mechanized to the degree that large programs can rely on consistent production of high numbers. (Need to give potential numbers). This enables large-scale production of NPV, sterile hybrid backcross insects, and parasitoids. Augmentation/suppression programs are being conducted to evaluate feasibility and efficacy.

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Research Gaps and Bottlenecks

1. Need increased persistence of microbials.
2. Lack of knowledge on efficiency of native and released beneficials.
3. Research on antogonistic organisms against natural enemies.
4. Lack of screening biological activity of natural substances produced by entomopathogens and other natural enemies.
5. More emphasis needed on mass rearing and production (Increased numbers, quality, etc.) when preparing for large area-wide programs, including hosts/parasites/predators/pathogens.

6. Increased research effort on monitoring impact and establishment of released insects.
7. Increased emphasis on technology transfer and acceptance by general public.
8. Lack of knowledge on genetic variation in adaptability.
9. Lack of network of exchange of active materials in biological control.
10. Ultimate goal is area-wide suppression; area-wide basis is a gap.

Constraints

1. Money.
2. Research Associate program for 2 years (50 for 2 years; instead of 100 for 1 year), and avoid recency requirement.
3. Knowledge of systematics in biocontrol agents and hosts.
4. Coordination (lack of) foreign and domestic research on Heliothis/Helicoverpa.

Action Area 5 - Biological Control

		Year 1	Year 2	Year 3	Year 4	Year 5
LEAD 5.1	Develop technology for managing Heliothis/Helicoverpa spp. using entomopathogens/ nematodes	Identify indigenous, exotic, or genetically altered entomopathogens considered most efficacious for field use in pest management systems, conduct laboratory and field experiments to examine effectiveness, and evaluate the compatibility of individual entomo-pathogens with various crop production practices	Continue as in yr 1; application, formu-lation, persistence	Identify most efficacious strategies for using specific entomopathogens for control or management, and conduct crop-wide cooperative field studies	Continue yr 3	Organize and develop techniques into pilot testing to demonstrate commercial probabilities of new products, strategies, or techniques of pest management
		CMI, AHM, PVV, JLR, MRB, GWE, JJH	SAME	SAME	SAME	SAME
SAFEGD 5.1.1	Develop efficacious methods for mass producing entomopathogens/ nematodes	Select specific pathogens considered potential candidates for future production; determine criteria for QC in production	Continue yr 1	Conduct trial mass productions of candidate entomo-pathogens in small laboratory systems for field use in efficacy trials; determine standard methods and develop QC program and evaluate for development of resistance	Continue yr 3 and identify those entomo-pathogens demonstrating greatest field efficacy and most likely candidates for commercial use; genetic characterization and identification	Determine technology required for the efficacious mass production of entomopathogens demonstrated as having commercial potential if production methodology was known
		CMI, MRB, JJH	SAME	SAME	SAME	SAME

Action Area 5 - Biological Control

		Year 1	Year 2	Year 3	Year 4	Year 5
OPTIM 5.1.2a	Improve efficacy through natural or genetic manipulation of entomopathogens	Conduct laboratory studies designed to demonstrate increased virulence, rate of mortality, host-range, and other positive attributes of specific entomopathogens under study for pest control	Continue yr 1, and conduct studies toward fulfilling safety data requirements	Determine broader characteristics of candidate entomo-pathogens for field use through cooperative studies, developing data to aid in future registration or patenting of product	Conduct small field trials to compare efficacy of improved entomopathogen to	Develop data needed to expand candidate entomopathogen to commercial production indigenous one and release
		CMI, AHM	SAME	SAME	SAME	SAME
OPTIM 5.1.2b	Develop formulation technology that will contribute to greatest field efficacy (entomo.); improve persistence to at least 7 days	Identify types of formulation needed in specific host-plant-entomopathogen relationship to obtain maximum effect	Conduct laboratory, greenhouse, and field trials to demonstrate attri-butes of formulation needed for specific entomopathogens	Determine field efficacy of candidate formulation through crop-wide cooperative tests	Continue yr 3	Determine commercial prospects of candidate formulations, including application technology, storage, and cost-effectiveness of use
		MRB, JJH	SAME	SAME	SAME	SAME
OPTIM 5.1.2c	Develop application technology for optimum field efficacy (entomo.) for particular regions of the country	Conduct laboratory, greenhouse, and field tests to develop methodology resulting in increased deposition of the specific entomopathogen on specific target areas through the development of new and innovative application equipment or techniques	Continue yr 1	Continue yr 1, developing systems to apply specific types of formulations, requiring aerial and ground application techniques	Continue yr 1, concentrating technology develop-ment in areas demonstrated as best candidates for acceptance by user target group as a practical and efficacious method	Demonstrate commercial probabilities of methodology developed through large field trials
		MRB, GWE, JJH, LDC, WWMS	SAME	SAME	SAME	SAME
SUPPL 5.1.3	Develop improved standard bioassays for determining bioactivity of entomopathogens	Conduct laboratory studies to compare accuracy of various methodology described for bioassaying entomopathogens	Identify the most acceptable procedures for each category of entomopathogen for determining bioactivity	Continue yr 4	Through cooperative interactions, produce standard methods of bioassay acceptable to most researchers and regulatory agencies	Continue yr 4
		CMI, MRB, JJH	SAME	SAME	SAME	SAME

Action Area 5 - Biological Control

		Year 1	Year 2	Year 3	Year 4	Year 5
LEAD 5.2	Develop technology for managing Heliothis/Helicoverpa spp. using parasites/predators	Develop plans for field evaluation of native and imported species of parasitoid; test feasibility of parasite/predator releases early-season vs. during growing season	Conduct field studies with treatments determined yr 1, parasite and predator together and separate; consider pesticide treatments	Repeat yr 2 or redesign if no differences seen; optimize input by managing habitat rather than releasing more insects	Implement management scheme with reduced pesticide use	Repeat yr 4
		TAC, MHG, WWMS, SMF, PDG, HO, JHT, JRR, JEC, HRG, JJH, WJL, ACC, EGK, WCN, DAN, JEP	SAME	SAME	SAME	SAME
SAFEGD 5.2.1a	Develop stable efficacious methods for mass production and quality control and release methods for parasites/predators	Determine criteria for QC; refine equipment for automation; develop strategy for contamination control	Determine standard methods and develop QC program; test release methods for optimal efficacy	Carry out QC program; improve release technology	Carry out QC program; refine rearing and release technology as it becomes standardized	Carry out QC program; define systems and capability
		MHG, JLR, HRG, DAN, EGK, JHT, SMF, JEP	SAME	SAME	SAME	SAME
SAFEGD 5.2.1b	Identify and characterize strains/species of native and introduced natural enemies of Heliothis/ Helicoverpa	Identify and characterize	Evaluate	Identify and characterize	Evaluate	Identify and characterize and evaluate
		MHG, CMI, AHM, WWMS, PVV	SAME	SAME	SAME	SAME
SUPPL 5.2.3a	Improve efficiency and persistence of parasites/predators through chemical/ behavioral ecology and genetic manipulation of parasites/ predators	Cooperative projects with other action areas	Continue cooperation	Continue cooperation	Continue cooperation	Continue cooperation
		MHG, WWMS, JHT, HRG, JJH, WJL, ACC, EGK, WJL, JEP	SAME	SAME	SAME	SAME

Action Area 5 - Biological Control

		Year 1	Year 2	Year 3	Year 4	Year 5
SUPPL 5.2.3b	In vitro rearing of parasites and predators	Isolate ovipositional stimulants and growth factors produced by host tissues and cell lines; study influence of teratocytes on larval growth	Characterize and identify ovipositional stimulants and growth factors released by cell lines, host tissues, and teratocytes toward improving growth and molting of parasitoids in vitro	Synthesize ovipositional kairomone and improve efficiency of artificial oviposition substrate; synthesize egg and larval growth factors chemically or biologically	Evaluate growth factors and ovipositional stimulants in and in vitro system and fine tune for mass rearing	Integrate 1-4 yrs into an artificial host on a mass rearing scale; incorporate related knowledge of in vitro mass rearing into system
		SMF, PDG, HO, JEC, HRG, WCN, ACC	SAME	SAME	SAME	SMF, PDG, HO, JR, JEC, WCN
SUPPL 5.2.3c	Rearing of predators	Expand in vivo/ in vitro rearing	Develop immunologic (ELISA) methods to identify prey consumption by predators (e.g., immunological detection, behavioral tests)	Fit predators (by search strategy life history profile, ecological performance) to control Heliothis/ Helicoverpa complex	Integrate predator use with HPR and other strategies	Use plant and prey substances to manipulate predators
		ACC	SAME	SAME	SAME	SAME
LEAD 5.3	Develop an IPM program emphasizing use of biocontrol practices and preservation of natural enemies in decision-making as part of integrated systems	Develop plans for implementation	Identify and select specific practices	Field assessment of selected practices with modifications, as needed	Same	Same

Action Area 5 - Biological Control

		Year 1	Year 2	Year 3	Year 4	Year 5
SAFEGD 5.3.1	Field assessment and fate of artificially applied/released entomopathogens and parasites/predators	Determine criteria for evaluating efficacy; develop monitoring technology; determine level of suppression expected; develop methods for determining fate of released NE	Make preliminary release to determine suppression level feasible	Based on yr 2, revise strategy and re-evaluate	Continue refining techniques and defining feasible approach	Conduct test with specific program goals
		MHG, CMI, PVV, MRB, GWE, JJH, JHT, JLR, WJL, WWMS, JEP	SAME	SAME	SAME	SAME
OPTIM 5.3.2	Improve rearing methods for host material for pathogens and for parasites/predators	Evaluate economics and environmental factors that influence biology, storage, etc.	Change methods to improve efficient use of time, space and materials	Define limits of production	Rear large test numbers and trouble-shoot system as it is tested	Continue yr 4
		CMI, JLR, MRB, DEH, JJH, WJL, HRG, JEC, JEP	SAME	SAME	SAME	SAME
SUPPL 5.3.3	Protection of successive crops by early application of entomopathogens and beneficial arthropods	Apply biotic agents into early successional annual crops; evaluate carry over of impact in subsequent crops	Continue	Continue	Put into IMP scheme	Continue
		MHG, PVV, MRB, JJH, HRG, JEP	SAME	SAME	SAME	SAME

Action Area 6 - Genetics, Molecular Biology, and Basic Physiology

Introduction

The tobacco budworm (Heliothis virescens) and the corn earworm (Helicoverpa zea) are pests on a wide variety of crops including cotton, corn, soybean, lettuce, tomato, tobacco, and other economic and ornamental plants. Currently, their control is achieved almost entirely through the use of synthetic organic insecticides. The desire to effectively manage Heliothis/Helicoverpa spp. using integrated control strategies that reduce pesticide dependency continues as a primary thrust of ARS scientists. Insect genetics, molecular biology, and basic physiology can provide major contributions to the discovery, development, and refinement of alternative management approaches for Heliothis/Helicoverpa spp. These contributions will be maximized if future investigations involving genetics, molecular biology, and physiology emphasize the following research areas: (1) the elucidation of the mechanism responsible for backcross sterility in H. virescens and the transfer of backcross sterility to H. zea, (2) the evaluation of backcross sterility as a control concept for H. virescens in the Mississippi delta area, (3) the crossbreeding of Helicoverpa spp. to develop backcross sterility in H. zea, (4) the potential use of inherited sterility as a control strategy for H. zea and H. virescens, (5) the development of genetic sexing systems for H. zea and H. virescens to eliminate the production of females, and (6) the elucidation of physiological and biochemical basis of development, diapause and reproduction in Heliothis/Helicoverpa.

Major Accomplishments

Studies in genetics, molecular biology, basic physiology, and developments in support science and technology have resulted in significant accomplishments which should enhance future success in developing control strategies for Heliothis/Helicoverpa spp. These recent accomplishments are listed by location.

Catalogue of Noctuidae of the world; revision of Heliothis virescens species group and higher classification of Helicoverpa. (Beltsville, MD)

Improved methods and techniques for releasing Heliothis backcross insects in area-wide release programs; determined that the attractancy of H. virescens backcross females to wild males was not adversely affected by continuous colonization in the laboratory. (Stoneville, MS)

Established mechanized production procedures to produce H. virescens, H. zea, and Heliothis backcross to evaluate proposed biological control concepts. (Mississippi State, MS)

Developed a multiple-technique approach for fingerprinting genetic structures of suspected migrants from Mexico and from U.S. resident populations of H. virescens and H. zea. This includes use of (1) isoenzymes, (2) mitochondrial DNA RFLP, (3) genomic DNA RFLP, and (4) polymorphism in DNA sequences amplified by PCR (Polymerase Chain

Reaction). Identified significant allele frequency differences of ADK, CK and PGM loci among populations of H. zea. Cloned two EcoRI fragments of mitochondria of H. virescens. Restriction digests of individual moths probed with mtDNA showed polymorphism in feral populations. Preliminary data suggest differences among geographical populations. Restriction analysis of PCR amplified DNAs showed extensive polymorphism in populations. Studies on limited samples showed interpopulational differences. (Fargo, ND)

Demonstrated the presence of Rickettsia-like Organisms (RLOs) in the testes of Heliothis virescens and F1 and early backcross generations (BC1, BC2) derived from the interspecific hybridization of H. virescens X H. subflexa. These bacteria-like organisms were also present in testes of Helicoverpa zea and F1 males derived from the cross H. zea X H. assulta.

Determined that wild-type populations of H. virescens and H. zea have microorganisms within the testes similar to those of laboratory-reared moths except that they are enclosed by a bacterial-like cell wall.

Discovered that Virus-like Particles (VLPs) are present in spermatocyst cell nuclei of all species of Heliothis and Helicoverpa examined to date (H. virescens, H. subflexa, Helicoverpa zea, H. assulta, H. punctigera, H. armigera), as well as in F1 and backcross testes resulting from crosses between some of the above species. The particles are more abundant in older males (6 day adults), and appear in native moths as well as in laboratory reared ones and are found among species of wide geographical distribution (Korea, Pakistan, Australia). (Fargo, ND)

Identified the surface lipids of diapausing H. virescens pupae. Discovered that these lipids were composed of equal amounts of long-chain fatty aldehydes and the corresponding fatty alcohols, and lesser amounts of wax esters. The was esters consisted of long-chain alcohols esterified to saturated and unsaturated fatty acids. (Fargo, ND)

Discovered novel very long-chain methyl-branched alcohols and their acetate esters in the internal lipids of developing H. virescens pupae. These compounds are essentially absent at the beginning and end of the pupal stage. They reach a maximum level just prior to the midpoint of the pupal stage and at this time are the lipids most actively synthesized. (Fargo, ND)

Investigated molecular aspects of sperm development in Heliothis virescens X H. subflexa backcross hybrids. Cloned portions of the H. virescens mitochondrial genome, discovered that four transcripts in backcross hybrid testes are not polyadenylated. Isolated and characterized mitochondrial chaperonin (hsp60) polypeptides; cloned and sequenced a gene encoding a sperm-specific isoform which exists as a unique net charge and/or molecular weight variant in all insect species screened. (Gainesville, FL)

Purified and characterized hemolymph storage proteins from H. virescens, cloned and sequenced their cognate cNDAs. Discovered that the gene for

one of these polypeptides, "p82", is also expressed in cells of the testis sheath; also that the p82 polypeptide is transported into differentiating spermatids and sequestered within their mitochondrial derivatives. (Gainesville, FL)

Discovered that the p82 storage protein and lipophorin are hemolymph riboflavin-binding proteins and determined various kinetic properties of flavin binding. Developed a flavin affinity matrix for the purification of this class of polypeptides and determined that several groups of insects express homologous polypeptides. Also discovered that testes and malpighian tubules contain large reserves of unbound riboflavin, and further, that these pools are neither dependent upon dietary flavin nor are metabolically interconnected with that in the hemolymph. (Gainesville, FL)

Demonstrated the effects of substerilizing doses of radiation and inherited sterility on Helicoverpa zea reproduction. Inherited deleterious effects resulting from irradiation of males and females were expressed for several generations. Laboratory and field studies on reproduction and survival indicated that the use of substerilizing doses of radiation and the resulting inherited sterility has a greater potential as a selective management strategy for H. zea than does the conventional 100% sterilizing dosage. (Tifton, GA)

Demonstrated the effects of substerilizing doses of radiation and inherited sterility on H. zea behavior. Studies revealed that irradiated (10 krad) and nonirradiated, laboratory-reared males released in the field or in field cages were not significantly different in their nocturnal behavior and mating propensity of females that had been mated with irradiated (10 krad) and nonirradiated males was not significantly different. (Tifton, GA)

Conducted a pilot test designed to study the efficacy of using inherited sterility for suppressing seasonal population increases of H. zea. Although data from this study have not been fully analyzed, preliminary results revealed a positive correlation between the distance from the release site of irradiated (10 krad) males and the number of wild males captured. Also, seasonal population curves of wild males captured and wild males estimated from mark-recapture data revealed that seasonal increases of wild H. zea males were reduced where irradiated males were released. (Tifton, GA)

Significance

Improved methods and techniques in Heliothis rearing and release technology will provide significant savings in the conduct of area-wide release programs to control Heliothis/Helicoverpa species. Pilot test studies demonstrated the potential of inherited sterility to suppress seasonal population increases of Helicoverpa zea. The discovery of Rickettsia-like organisms (RLOs) and Virus-like particles (VLPs) in the testes of backcross sterile males, and the characterization of mitocondrial chapronin polypeptides and hemolymph riboflavin binding storage proteins (both of which express in testis) should now enable scientists to identify the mechanism of backcross sterility. The

development of baseline genetic information on mtDNA RFLP, allozymes and PCR amplification profiles in H. zea and H. virescens should aid in determining the origin of migrant moths and their contribution to population dynamics in U.S. agricultural habitats.

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Research Gaps and Bottlenecks

Gaps

1. Molecular basis of insecticide resistance: This knowledge is needed for use of insecticide resistance gene as a selectable marker in high priority research including monitoring of feral populations for insecticide resistance, development of genetic sexing procedures and germline transformation methods. Bottleneck: None identified.

2. Quick and effective method for distinguishing eggs and larvae of Heliothis virescens from those of Helicoverpa zea: Currently, it is not possible to identify pest species (from eggs and larvae) responsible for fresh infestations in the field. This knowledge is necessary for rapid field identification of pest species, so that appropriate control measures can be applied. [SM]
Bottleneck: None predicted

3. Automation of sexing (by genetic and molecular methods): The purpose is to develop methods for accurate and rapid sexing of pupae or adults (or of earlier developmental stages). This research is an important requirement for developing technology for mass propagation, processing and distribution of Heliothis and Helivoverpa species. It would enhance the effectiveness of backcross sterility and inherited sterility as a component of Area Wide Integrated Pest Management Strategies. Genetic and molecular approaches to sexing would involve cloning, characterization and in situ localization of sex-specific genes, and establishment of linkage groups and genetic maps of markers - mutants, allozymes and polymorphic DNA sequences.
Bottleneck: Lack of germ-line transformation method for Heliothis and Helicoverpa.

4. Quality control of mass-reared insects: Genetic (and other) methods are needed for assessment of quality of mass-reared and genetically altered moths (with inherited or backcross sterility) to assure their interacting and competing with wild moths. The quality assessment may include information on pheromone production, post-treatment sterility, longevity, mating performance, mating preference, flight and genetic variability.
Bottleneck: None identified.

5. Rapid methods for estimating the spread of backcross sterility factors (distinguishing backcross sterile insects and their progeny from native insects) into the native population.
Bottleneck: None identified.

6. Methods (genetic engineering) for achieving inherited sterility or other deleterious effects without the use of irradiation: This research is needed to avoid the damaging effects of irradiation affecting quality of sterile insects. Non-radiation sterility methods will enhance the effectiveness of genetic control as a component of the Area Wide Integrated Pest Management Strategies.

Bottleneck: Germ-line transformation method for Heliothis/Helicoverpa.

7. Improved methods for synchronous rearing of Heliothis and Helicoverpa species: There is a need to develop improved rearing techniques for the purpose of providing sufficient numbers of insects synchronized to the same stage(s) of development. Availability of synchronized larvae and pupae of the same physiological age is important for successfully conducting:
   a) tests of plant germplasm for insect resistance;
   b) comparative studies on hormonal regulation of key physiological and biochemical processes responsible for:
      1) storage and excretion of toxic nitrogenous waste products;
      2) synthesis and deposition of cuticular lipids;
      3) synthesis of novel methyl-branched alcohols in pupae.

   Bottlenecks: None

Research Constraints

Scientists in the Genetics, Molecular Biology, and Basic Physiology Action Area are involved in a diverse group of research projects and therefore, confronted with a variety of constraints to achieving research goals. Although insufficient funds and/or manpower are a common constraint for many research projects, other more specific constraints are as follows:

Rearing Heliothis/Helicoverpa spp.: Automated equipment and facilities are limited and rearing costs are high.

Pilot Study on BCS: The pilot study will be conducted over a 9 mi. x 9 mi. area in the Mississippi Delta. Due to the high costs of rearing and labor, appropriations do not permit replication of the release area within years. Also, adverse weather conditions during the release could seriously affect moth emergence.

Development of Helicoverpa BCS: The critical need is to import foreign Helicoverpa species into the Stoneville Research Quarantine Facility to conduct crossing trials and search for hybrid sterility. These exotic species must be obtained through foreign exploration or through foreign cooperators. Foreign cooperators have not been a good source, and it is difficult to find a qualified person and support for conducting foreign explorations. Expenses for one exploration, including salary, is approximately $8,000.

Genetic Structure of Heliothis/Helicoverpa Populations: Though circumstantial evidence overwhelmingly support the mass migration of Heliothis virescens and Helicoverpa zea, there are not suitable markers which would allow distinction between migrant and local populations. Attempts by investigators to identify the major origination habitats (source populations and cropping systems) of immigrants have been only partially successful. In addition, an estimation of the levels of migration by indirect methods is difficult to interpret. Attempts to determine the origin of migrants using trajectory analysis, have been

only partially successful. The impact of immigrant populations on pest dynamics of local populations remains unknown.

Microbial Mechanism of BCS: Definitive proof of the role of microbials in backcross sterility would involve mimicking the effect in backcross males (i.e., destruction of the eupyrene sperm mitochondrial derivative). Techniques will have to be developed to transfer these microorganisms interspecifically (egg injection, incorporation into tests in culture, etc.).

Transfer of BCS to Helicoverpa: Although researchers in our laboratory have found that male sterility is due to abnormal sperm production and transfer, the nature of causative factors remains unknown. Nothing is known on the mechanism of backcross sterility in Heliothis virescens. Currently, it is not possible to induce backcross sterility in Helicoverpa zea.

Strain-specific RLO Variants: Screenings of field populations would require the establishment of an extensive collaborative network.

Action Area 6 - Genetics, Molecular Biology, and Basic Physiology

		Year 1	Year 2	Year 3	Year 4	Year 5
Backcross Sterility						
LEAD 6.1	Mechanisms of backcross sterility (BCS) in *Heliothis virescens* and transfer of BCS to *Helicoverpa zea*	Initiate taxonomic identification and molecular, biochemical, and ultrastructure characterization of Rickettsia-like Organisms (RLO)	Continue characterization of RLOs	Initiate studies on mode of transmission of RLOs and determine the biochemical role of RLOs in reproductive processes	Continue as in yr 3 and initiate RLO transfer into *H. zea*	Continue transfer technology and develop BCS delivery system
		MED, CMK, SKN	SAME	MED, SKN	SAME	SAME
SAFEGD 6.1.1	Genetic relatedness of RLOs and VLPs of *H. zea*, *H. virescens*, and *H. subflexa*	DNA sequence information on RLO of *H. zea*, *H. virescens* and *H. subflexa*. Initiate DNA or RNA sequences on virus-like particles (VLP)	Compare RLOs and VLPs of *H. virescens*, *H. subflexa*, and *H. zea*	Analyze sequence data to determine roles (transposons) of RLOs and VLPs	Continue sequence analysis to identify specific conserved regions among RLO and VLPs of *H. virescens*, *H. subflexa*, and *H. zea*	Complete task of yr 4 and determine interrelationship between microbe and host genome
		MED, CMK, SKN	SAME	MED, SKN	SAME	SAME
OPTIM 6.1.2	Determine role(s) of microbes in symbiosis and backcross sterility	Initiate development of aposymbiant strains of *Heliothis* spp.	Continue as in yr 1 and initiate culturing of RLOs and determine role of RLOs in riboflavin synthesis	Establish cultures of RLOs and determine regions of genome involved symbiosis and BCS	Initiate DNA sequencing of regions identified during yr 4	Complete DNA sequencing work
		SGM, CMK	SGM	MED, SKN	SAME	SAME
SUPPL 6.1.3	Initiate artificial insemination studies between *Heliothis* spp. and *Helicoverpa zea* and examine the progeny for BCS					

Action Area 6 - Genetics, Molecular Biology, and Basic Physiology

		Year 1	Year 2	Year 3	Year 4	Year 5
LEAD 6.2	Evaluate BCS as a control concept for H. virescens in the Mississippi Delta area	Initiate a pilot test over a 9 mi x 9 mi area by releasing BC males and females in the spring. Incorporate quality control measures into the mass rearing technology	Repeat BC releases as in yr 1. Continue improving mass rearing technology and maintaining quality control	Evaluate data from pilot test	Pilot test terminated. Direct research to meet operational objectives designated by industry. Major efforts to be directed for competitive costs and acceptable shipping and dispersal methods. Maintain current technology transfer programs with other USDA rearing laboratories	Expand technology transfer programs with industry to enhance applied use of tested biological control programs. Maintain active technology transfer program with other USDA insect production laboratories to better utilize spin-off rearing technologies useful to other research projects
		MLL, JLR	SAME	SAME	JLR	SAME
SAFEGD 6.2.1	Improve mass rearing and population monitoring technology for H. virescens	Initiate large field study to evaluate methods and techniques for releasing and monitoring Heliothis backcross insects in area-wide release programs. Establish a technology transfer action plan with industry to identify commercial potential of technologies developed. Expand technology transfer to other USDA/State research groups assigned production for expanded programs	Continue evaluation of releasing and monitoring techniques as in yr 1. Establish lab/field release feedback system to reduce handling stress of field-released insects. Develop compatible mechanized insect rearing systems with USDA, APHIS insect production laboratories to assure production capabilities with program expansion	Continue as in yr 2. Critique production and field release processes to reduce cost and increase control effects for field-released insects. Test advanced processing equipments to process and assemble insect rearing trays	Direct research to meet operational objectives designated by industry. Major efforts to be directed for competitive costs and acceptable shipping and dispersal methods. Maintain current technology transfer programs with other USDA insect rearing laboratories	Expand technology transfer programs with industry to enhance applied use of tested biological control programs. Maintain active technology transfer program with other USDA insect production laboratories to better utilize spin-off rearing technologies useful to other research projects
		MLL, JLR	SAME	SAME	SAME	SAME

Action Area 6 - Genetics, Molecular Biology, and Basic Physiology

		Year 1	Year 2	Year 3	Year 4	Year 5
OPTIM 6.2.2	Develop a genetic sexing system for H. virescens for production of BC progeny	Isolate two independent, sex-linked conditional lethal mutants, and/or clone sex-specific genes which express early during development. Initiate research on germ-line transformation technology	Continue as in yr 1 to induce conditional lethal mutants, and/or initiate the isolation and characterization of the promotor region of the sex-specific gene(s). Continue germ-line transformation research	Conduct linkage group studies on conditional lethal genes and select for closely linked loci, and/or continue characterization of promotor sequence and develop a hybrid construct containing a promotor, a deleterious coding sequence and a marker gene. Continue germ-line transformation research	Test the conditional genetic sexing strain under selective conditions, and/or test the efficiency and function of the hybrid construct by germ-line transformation method, if one has been developed, or by transfection of tissue culture cell lines. Continue fine-tuning germ-line transformation research	Test the stability of genetic sexing strains under mass rearing conditions. Continue fine-tuning germ-line transformation research
LEAD 6.3	Crossbreeding of Helicoverpa spp. to develop BCS in H zea	Obtain Helicoverpa spp. from the U.S. and foreign countries and initiate crossbreeding with H. zea	Continue collections of Helicoverpa spp., and continue crossbreeding with H. zea until a cross resulting in BCS is obtained. Evaluate the stability of the BCS for at least 10 generations	Continue as in yr 2	Continue as in yr 3	Continue as in yr 4
		MLL, RWP	SAME			
SAFEGD 6.3.1	Obtain biosystematic and hybridization information on Helicoverpa spp. for future reference	Initiate biosystematic investigations on Heliothinea, and obtain hybridization relationships between Helicoverpa spp. and H. zea	Continue hybridization studies as long as new species are available	Continue as in yr 2	Continue as in yr 3	Continue as in yr 4
		MLL, RWP	SAME			

Action Area 6 - Genetics, Molecular Biology, and Basic Physiology

		Year 1	Year 2	Year 3	Year 4	Year 5
Inherited Sterility						
LEAD 6.4	Potential use of inherited sterility as a control strategy for H. zea	Initiate studies to determine the effects of inherited sterility and substerilizing doses of radiation on H. zea courtship behavior and flight propensity, and on H. zea spermatogenesis and sperm transfer	Continue studies on the interaction of inherited sterility and H. zea behavior and physiology, and initiate studies to examine the compatibility of inherited sterility in H. zea with other control strategies	Complete studies on H. zea behavior and physiology, and continue studies on the compatibility of inherited sterility and other control strategies	Initiate preliminary field trials combining inherited sterility with other control strategies	Continue field trials combining inherited sterility with other control strategies
		JEC	JEC, HRG	JEC, HRG, BRW, LDC	JEC, HRG, LDC	JEC, HRG, LDC, BRW
SAFEGD 6.4.1	Effects of inherited sterility on H. zea physiology, behavior, and reproduction	Initiate studies to determine the effects of inherited sterility and substerilizing doses of radiation on H. zea flight propensity	Complete studies on the interaction of inherited sterility and H. zea flight propensity and initiate studies on the effect of inherited sterility and substerilizing doses of radiation on H. zea testes	Complete studies on the effects of inherited sterility on H. zea testes and initiate lab studies on the interaction of inherited sterility and other control strategies	Continue lab studies on the interaction of inherited sterility and other control strategies	Continue previous yr
		JEC	SAME	JEC, HRG	JEC, HRG, BRW, LDC	
OPTIM 6.4.2	Develop a genetic sexing system for H. zea to eliminate the production of females	Isolate two independent, sex-linked conditional lethal mutants, and/or clone sex-specific genes which express early during development	Continue as in yr 1 to induce conditional lethal mutants, and/or initiate the isolation and characterization of the promotor regions of the sex-specific gene(s)	Conduct linkage group studies on conditional lethal genes and select for closely linked loci, and/or continue characterization of promotor sequence and develop a hybrid construct containing a promotor, a deleterious coding sequence, and a marker gene	Test the conditional lethal genetic sexing strain under selective conditions, and/or test the efficiency and function of the hybrid construct by germ-line transformation method or by transfection of tissue culture cell lines	Test the stability of genetic sexing strains under mass rearing conditions

Action Area 6 - Genetics, Molecular Biology, and Basic Physiology

		Year 1	Year 2	Year 3	Year 4	Year 5
SUPPL 6.4.3	Study the response of H. virescens to substerilizing doses of radiation	Determine the effects of substerilizing doses of radiation and inherited sterility on H. virescens fecundity, egg hatch, and mortality	Continue as in yr 1	Determine the effects of substerilizing doses of radiation and inherited sterility on field survival, diapause, and mating and sperm competitiveness	Continue as in yr 3	Continue as in yr 4
Genome Mapping						
LEAD 6.5	Establish linkage groups and genetic maps of morphological mutants, allozymes, and DNA sequences	Establish genetic mutant stocks, determine which isozyme loci are polymorphic in feral population, conduct genetic crosses to establish linkage groups, and begin construction of a genomic library. Initiate isolating clones by using heterologous gene probes SKN, HO	Continue genetic crosses to map genes (allozymes and morphological mutants), complete construction of genomic library and continue isolating clones of known sequences using Drosophila genes as probes with emphasis on genes that determine reproductive, physiological, and developmental processes, germ-line differentiation, and also inducible and transposable genes	Continue genetic mapping, characterize clones, and determine which of the cloned sequences are polymorphic (RELP) in feral populations	Map the cloned genes relative to allozyme loci and morphological mutants	Complete linkage group analysis and genetic mapping of all the genes identified in previous 4 years
SAFEGD 6.5.1	Ontogenetic and epigenetic effects on expression of genetic markers, gene mapping	Establish ontogenetic changes in the expression of allozymes of various loci	Establish the effects of age, sex, and diet on the expression of allozymes of various loci	Isolate additional morphological mutants and recessive lethals by breeding, alkylating agents, and radiation	Map new morphological mutants found in yr 3	Complete ontogenetic and epigenetic studies on expression of genetic markers, gene mapping

Action Area 6 - Genetics, Molecular Biology, and Basic Physiology

		Year 1	Year 2	Year 3	Year 4	Year 5
OPTIM 6.5.2	Characterize genes in terms of their expressions during life cycle of the insects and tissue specificity	Isolate total RNA from different developmental stages, and enrich for mRNA, prepare northern blots and initiate probing blots with cloned genes (isolated in 6.5)	Continue as in yr 1 using different gene clones	Continue as in yr 1 and 2, and establish developmental stage profile for genes. initiate RNA isolation from different tissues	Probe northern blots of tissue-specific mRNA with cloned genes	Complete developmental and tissue-specific expression of genes
LEAD 6.6	Identify the physiological and biochemical basis of insect development, diapause, and reproduction as a component of area wide management	Determine the timing of uric acid storage in pupal fat body and its subsequent release in the adult; identify the structures of cuticular lipids in diapausing/developing H. virescens, and of novel very long-chain methyl-branched alcohols and their esters in the internal lipids of pupae DRN, JSB	Purify and characterize urate storage granules; compare the composition of surface lipids in other Lepidoptera, and the occurrence/composition of the novel internal alcohols and their esters in other Lepidoptera and in other orders of insects DRN, JSB	Characterize the biocellular structures for uric acid storage and release from the fat body; determine the biosynthetic sites, precursors, and enzyme systems responsible for the synthesis of surface lipids and of the internal methyl-branched alcohols DRN, JSB	Continue as in yr 3	Continue as in yr 4
SAFGD 6.6.1	Identify fundamental biochemical processes in insects	Determine the timing of uric storage in pupal fat body; identify the structures of cuticular lipids in diapausing H. virescens or M. sexta, and of novel very long-chain methyl-branched alcohols and their esters in the internal lipids of M. sexta DRN, JSB	Purify urate storage granules; compare the composition of surface lipids and of the novel internal alcohols and their esters in other Lepidoptera DRN, JSB	Characterize the subcellular structures for uric acid storage and release from the fat body; determine the biosynthetic sites, precursors, and enzyme systems responsible for the synthesis of surface lipids and of the internal methyl-branched alcohols	Continue as in yr 3	Continue as in yr 4

Action Area 6 - Genetics, Molecular Biology, and Basic Physiology

		Year 1	Year 2	Year 3	Year 4	Year 5
OPTIM 6.6.2	Characterize the key physiological and biochemical systems responsible for the synthesis and function of uric acid and of internal and cuticular lipids	No activity	With assistance of postdoctoral associates, develop an in vitro system to characterize the biosynthetic pathway, determine the source and availability of precursors, characterize key enzymes, identify biosynthetic inhibitors, determine the metabolic fate and function of these compounds and whether they can be manipulated to interfere metamorphosis DRN, JSB	Continue as in yr 2	Continue as in yr 3	Continue as in yr 4
SUPPL 6.6.3	Characterize the enzyme systems and the physiological functions and fate of insect cuticular lipids, internal methyl-branched alcohols, and nitrogenous waste products	No activity	No activity	Develop in vitro systems to characterize precursors, cofactors, and key enzymes. Elucidate mechanisms and hormonal control of the enzyme systems responsible for formation and dissolution of urate granules, for the synthesis, transport and function of long-chain surface lipids, and for the synthesis, physiological role, and metabolic fate of the novel internal long-chain methyl-branched lipids DRN, JSB	Continue as in yr 3	Continue as in yr 4

Appendix A. Committee Memberships

HELIOTHIS/HELICOVERPA WORKSHOP

CHAIRMAN - D. D. Hardee, Stoneville, MS
COORDINATOR OF WORKING PLAN - J. E. Powell, Brookings, SD

Steering Committee

J. R. Coppedge, NPL
Beltsville, MD

R. M. Faust, NPL
Beltsville, MD

R. S. Soper, NPL
Beltsville, MD

D. D. Hardee
Stoneville, MS

A. C. Bartlett
Phoenix, AZ

H. M. Gross
Tifton, GA

T. J. Henneberry
Phoenix, AZ

P. D. Lingren
College Station, TX

H. Oberlander
Gainesville, FL

J. E. Powell
Brookings, SD

Co-Coordinators

Action Area 1 - Host Plant Resistance
W. L. Parrott, Mississippi State, MS
B. R. Wiseman, Tifton, GA

Action Area 2 - Chemical Control and Application Technology
L. D. Chandler, Tifton, GA
I. W. Kirk, College Station, TX

Action Area 3 - Ecology and Population Dynamics
J. R. Raulston, Weslaco, TX
T. L. Wagner, Mississippi State, MS

Action Area 4 - Behavior Modifying Chemicals
E. R. Mitchell, Gainesville, FL
T. N. Shaver, College Station, TX

Action Area 5 - Biological Control
M. R. Bell, Stoneville, MS
S. M. Ferkovich, Gainesville, FL

Action Area 6 - Genetics, Molecular Biology, and Basic Physiology
J. E. Carpenter, Tifton, GA
S. K. Narang, Fargo, ND

Registration and Local Arrangements Committee

J. R. Coppedge
Beltsville, MD

P. D. Lingren
College Station, TX

J. D. Lopez
College Station, TX

J. R. Raulston
Weslaco, TX

Appendix B. Workshop Agenda

Heliothis/Helicoverpa Workshop
Revise and Update National Plan

St. Anthony Hotel
300 E. Travis
San Antonio, Texas

September 16-19, 1991

Monday, September 16

1:00 - 7:00 p.m.	Registration - Anacacho Foyer
7:30 - 9:00 p.m.	Steering Committee, National Program Staff, Co-Coordinators - LaFitte Room

Tuesday, September 17

7:00 - 12:00 Noon	Registration - Anacacho Foyer

Opening Session - Anacacho

Moderator - D. Hardee

8:30 a.m.	Introductory Comments - D. Hardee
8:35 a.m.	Welcome - Earl King
8:40 a.m.	Objectives and Charge to Workshop - J. Coppedge and R. Faust
8:55 a.m.	Historical Perspective of National Heliothis Suppression Plan - J. Menn
9:05 a.m.	Comments from Industry - D. Allemann
9:20 a.m.	Comments from Consultants - R. Green
9:35 a.m.	Comments from National Cotton Council - A. Jordan
9:50 a.m.	Discussion
10:00 a.m.	Break - Balcony

Action Area 1 - Host Plant Resistance

Moderator - W. Parrott

10:30 a.m.	HPR in Corn - B. Wiseman
10:50 a.m.	HPR in Soybean - L. Lambert
11:10 a.m.	HPR in Cotton - W. Meredith
11:30 a.m.	HPR and Transgenic Plants - J. Jenkins
11:50 a.m.	Discussion
12:00 Noon	Lunch

Action Area 2 - Chemical Control and Application Technology

Moderator - I. Kirk

1:30 p.m.	History of Heliothis/Helicoverpa Control - J. Phillips
1:50 p.m.	Influence of Regulatory Agencies - P. Martin
2:05 p.m.	Chemigation - L. Chandler
2:20 p.m.	Application Technology - F. Bouse
2:35 p.m.	Status of Resistance - G. Elzen
2:50 p.m.	Discussion
3:00 p.m.	Break - Balcony

Action Area 3 - Ecology and Population Dynamics

Moderator - J. Raulston

3:30 p.m.	Biology and Ecology: Know and Don't Know - J. Graves
3:45 p.m.	Movement - W. Wolf
4:00 p.m.	Dynamics of Source Populations - J. Raulston
4:15 p.m.	Modeling: Know and Don't Know - T. Wagner
4:30 p.m.	Genetic Fingerprinting - S. Narang
4:40 p.m.	Experiences in Genetic Marking - A. Bartlett
4:50 p.m.	Discussion
5:00 p.m.	Adjourn

Wednesday, September 18 - Anacacho

Action Area 4 - Behavior Modifying Chemicals

Moderator - E. Mitchell

8:30 a.m.	Pheromones - J. Tumlinson
8:45 a.m.	Plant Chemicals - T. Shaver and R. Teranishi
9:05 a.m.	Area-Wide Suppression with Attracticides - P. Lingren
9:20 a.m.	Traps - J. Lopez
9:35 a.m.	Kairomones - J. Lewis
9:50 a.m.	Discussion
10:00 a.m.	Break - Balcony

Action Area 5 - Biological Control

Moderator - S. Ferkovich

10:30 a.m.	Pilot Tests for 1992 - D. Hardee
10:40 a.m.	Area-Wide Use of NPV - R. Bell
11:00 a.m.	Mass-Rearing - J. Roberson
11:20 a.m.	Nematodes - E. Cabanillas
11:35 a.m.	In-Vitro Rearing of Parasites - W. Nettles
11:50 a.m.	Discussion
12:00 Noon	Lunch

Action Area 6 - Genetics, Molecular Biology, and Basic Physiology

Moderator - S. Narang

1:20 p.m.	Taxonomy - R. Poole
1:30 p.m.	Basic Physiology - D. Nelson
1:40 p.m.	Molecular Biology - S. Miller
1:55 p.m.	Control of Sex Pheromone Production - A. Raina
2:10 p.m.	Inherited Sterility - J. Carpenter
2:25 p.m.	Backcross Sterility - M. Laster

2:40 p.m.	Backcross Sterility and Microbes: Molecular Approach - M. Degrugillier
2:50 p.m.	Discussion
3:00 p.m.	Break - Balcony
	Moderator - D. Hardee
3:30 p.m.	General Discussion, Instructions for Breakout Sessions
5:00 p.m.	Adjourn
6:00 p.m.	Attitude Adjustment
7:30 p.m.	Dinner - Georgian Moderator - Ed King Keynote Speaker - Ms. Gen Long, Vice-President for Communications, American Ag Women, and Member, Users Advisory Board, Mission, Texas

Thursday, September 19

8:30 a.m.	Breakout Sessions Action Area 1 - Bowie Action Area 2 - Alamo Action Area 3 - LaSalle
10:00 a.m.	Break - Outside Bowie
10:30 a.m.	Breakout Sessions Action Area 4 - Alamo Action Area 5 - LaSalle Action Area 6 - Bowie
12:00 Noon	Adjourn
1:30 p.m.	Working Session for Steering Committee, National Program Leaders, Co-Coordinators - Prepare National Plant (LaFitte)

Appendix C. ARS Scientists Working on Heliothis/Helicoverpa

ARS Area & Location	Scientist	Action Areas	Total SY
Beltsville Area			
Beltsville, MD	Poole, R. W.	6	0.3
	Raina, A. K.	4	1.0
Midsouth Area			
Mississippi State, MS	Jenkins, J. N.	1	0.1
	Olsen, R. L.	3	0.2
	Parrott, W. L.	1	0.9
	Roberson, J. L.	5 & 6	0.8
	Wagner, T. L.	3	0.3
	Willers, J. L.	3	0.4
Stoneville, MS	Bell, M. R.	5	1.0
	Elzen, G. W.	2 & 5	1.0
	Hardee, D. D.	5	0.3
	Hendricks, D. E.	3 & 4	1.0
	Lambert, L.	1	0.1
	Laster, M. L.	6	1.0
	Meredith, W. R.	1	0.1
	Mulrooney, J. E.	2	0.5
	Powell, J. E.	5	1.0
	Scott, W. P.	2	0.4
	Womac, A. R.	2	0.2
Midwest Area			
Ames, IA	Wilson, R. L.	1	0.2
Peoria, IL	Dowd, P. F.	2	0.2
Columbia, MO	Barry, B. D.	1	0.1
	Coudron, T. A.	5	0.2
	Darrah, L. L.	1	0.1
	Greenstone, M. H.	3 & 5	0.8
	Ignoffo, C. M.	5	0.8
	McIntosh, A. H.	5	0.9
	Rice, W. C.	5	1.0
	Steiner, W. W. M.	5	0.6
Northern Plains Area			
Fargo, ND	Buckner, J. S.	6	0.3
	Degrugillier, M. E.	6	1.0
	Krueger, C. M.	6	1.0
	Narang, S. K.	3 & 6	0.5
	Nelson, D. R.	6	0.3

Pacific West Area

Phoenix, AZ	Bartlett, A. C.	2 & 3	0.3
	Cohen, A. C.	5	0.4
	Henneberry, T. J.	2	0.1
Albany, CA	Eash, J. A.	1	0.5
	Elliger, C.	1	0.5
	Kint, S.	4	0.5
	Light, D. M.	4	0.5
	Teranishi, R.	3 & 4	0.2
	Waiss, A. C.	1	0.5
Fresno, CA	Vail, P. V.	5	0.3

South Atlantic Area

Gainesville, FL	Doolittle, R. W.	4	0.1
	Ferkovich, S. M.	5	1.0
	Greany, P. D.	5	0.5
	Heath, R. R.	4	0.2
	Mayer, M. S.	4	0.1
	McLaughlin, J. R.	4	0.3
	Miller, S. G.	6	1.0
	Mitchell, E. R.	4	0.3
	Oberlander, H.	5 & 6	0.2
	Tea, P. E. A.	4	0.8
	Tingle, F. C.	4	0.8
	Tumlinson, J. H.	4 & 5	0.4
Athens, GA	Schlotzhauer, W. S.	4	0.1
	Severson, R. F.	1 & 4	0.7
	Snook, M. E.	1 & 4	0.2
Tifton, GA	Carpenter, J. E.	5 & 6	0.5
	Chandler, L. D.	2, 5, 6	0.6
	Gross, H. R.	4, 5, 6	0.8
	Hamm, J. J.	5	0.5
	Lewis, W. J.	4 & 5	0.8
	Lynch, R. E.	1	0.1
	Sumner, H. R.	2	0.5
	Widstrom, N. W.	1	0.4
	Wiseman, B. R.	1 & 6	0.5
Oxford, NC	Jackson, D. M.	1 & 4	1.0

Southern Plains Area

Lane, OK	Pair, S. D.	3 & 4	0.3
College Station, TX	Altman, D. W.	1	0.7
	Beerwinkle, K. R.	3 & 4	1.0
	Bouse, L. F.	2	0.2
	Kirk, I. W.	2	1.0
	Latheef, M. A.	2	1.0
	Lingren, P. D.	3 & 4	1.0
	Lopez, J. D.	3 & 4	1.0
	Shaver, T. N.	3 & 4	1.0
	Westbrook, J. K.	3 & 4	1.0
	Wolf, W. W.	3	1.0
Weslaco, TX	King, K. G.	5	0.1
	Nettles, W. C.	5	0.1
	Nordlund, D. A.	5	0.1
	Raulston, J. R.	3, 4, 5	0.7
	Wolfenbarger, D. A.	2 & 4	1.0

Grand Totals: 85 Scientists; 17 Locations; 44.7 SY's.

Appendix D. List of Attendees

HELIOTHIS/HELICOVERPA WORKSHOP
San Antonio, Texas
September 16-19, 1991

Don Allemann
Ciba-Geigy
P. O. Box 11422
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WWAREC Box 128
Lane, OK 74555

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USDA, CSRS
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